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A

MANUAL

OF

NATURAL PHILOSOPHY:

WITH

RECAPITULATORY QUESTIONS ON EACH CHAPTER;

AND

A DICTIONARY OF PHILOSOPHICAL TERMS.

BY

JOHN L. COMSTOCK M.D.

AND

RICHARD D. HOBLYN A.M. OXON.

AUTHOR OF A

“DICTIONARY OF TERMS USED IN MEDICINE AND THE COLLATERAL SCIENCES,”

AND OF MANUALS OF CHEMISTRY AND OF THE STEAM ENGINE.

ONE STEEL PLATE AND 281 WOOD CUTS.

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1846.

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BIBLIOTHECA · BODLEIANA ·
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GLASGOW:—E. KHULL, PRINTER TO THE UNIVERSITY.

TO

MARSHALL HALL, JUN., ESQ.,

THIS WORK,

INTENDED TO PROMOTE THE ACQUISITION OF

NATURAL PHILOSOPHY,

THE SCIENCE IN WHICH HE HAS DISPLAYED

SUCH EARLY TALENT,

IS

AFFECTIONATELY DEDICATED.

ADVERTISEMENT.

This Manual of Natural Philosophy claims no higher merit than that of being a republication of the popular treatise by Dr Comstock, of Hartford, in the United States, enlarged and to a certain extent remodelled. His colleague feels a peculiar pleasure in the association of his own name with that of an author who has earned a well-merited reputation in the pursuit of physical science. As an elementary work, requiring for its perusal no mathematical attainment, nor, indeed, any previous knowledge of natural philosophy, it is at once simple, intelligible, and in most parts familiar. Terms of science have been in general avoided, and, when used, have been explained in connexion with the matters to which they relate; whilst the several subjects are illustrated, as much as possible, by means of common occurrences, with the view of placing philosophical truths within the reach of ordinary acquirements, and of rendering their study more inviting as a branch of general education.

"Every one," observes Dr Comstock, "who has attempted to make himself master of a difficult proposition by means of diagrams, knows that the great number of letters of reference with which they are sometimes loaded, is often the most perplexing part of the subject, and particularly when one figure is made to answer several purposes, and is placed at a distance from the explanation. To avoid this difficulty, the author has introduced additional figures to illustrate the different parts of the subject, instead of referring back to former ones, so that the student is never perplexed with many letters on any one figure. The figures are also placed under the eye, and in immediate connexion with their descriptions, so that the letters of reference in the text, and those on the diagrams, can be seen at the same time."

The additions which have been made in this manual to the treatise of Comstock, extend to about one hundred pages. It was found expedient to supply an entire chapter on the subject of heat, as the agent which remarkably modifies the properties of matter; and to insert a section on the steam engine, so as to convey a general idea of its principle of action, its construction, and its power. It was also thought desirable to introduce numerous passages in various parts of the work, as further explanatory or illustrative of the several subjects of which it treats. The original and the inserted matters may be readily distinguished: every paragraph, quoted by inverted commas, is the genuine work of Comstock, unless otherwise specified; for every sentence, not so particularized, the English author is responsible.

It is almost needless to recommend the study of a science, which has for its object the investigation of the laws of Nature, and which addresses itself to every thoughtful and intelligent mind by the earliest impressions of which our senses are susceptible. The fall of an apple to the ground may lead, and indeed has led, to the contemplation of the laws which regulate the motions of the planetary bodies; the position of a pebble in a rock may suggest considerations of the state of our globe, at periods antecedent to its historical epoch, or to its occupation by beings in any way resembling ourselves; nor should it be forgotten that, by means of a paper kite and a piece of wire, the sagacious Franklin discovered that thunder and lightning are only terrible phenomena of electricity.

There is yet another word. The subject is full of *promise.* A thousand questions are continually occurring, which the natural philosopher alone has the desire or power of solving. The inquiry becomes more and more exciting, and still new objects of wonder and research present themselves. "Science," observes Sir J. Herschel, "in relation to our faculties, still remains boundless and unexplored, and, after the lapse of a century and a half from the era of Newton's discoveries, during which every department of it has been cultivated with a zeal and energy which have assuredly met their full return, we remain in the situation in which he figured himself—standing on the shore of a wide ocean, from whose beach we may have culled some of those innumerable beautiful productions it casts up with lavish prodigality, but whose acquisition can be regarded as no diminution of the treasures that remain."

R. D. H.

January, 1846.

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NATURAL PHILOSOPHY.

CHAP. I.

THE PROPERTIES OF BODIES.

1. NATURAL PHILOSOPHY is a comprehensive term, including all those branches of physical science which treat of matter, its properties, and its motions. *Matter* is the general designation of all substances possessing weight, as distinguished from light, heat, and electricity, which, being destitute of appreciable weight, are commonly termed "imponderable agents." It is possible to conceive that a portion of matter, as a grain of sand, may be divided into a million parts, and each of these into a million more, and so on *ad infinitum*. It may, however, be true that a grain of sand cannot be divided into more than a certain number of parts, each of which, though invisible under our microscopes, possesses such cohesive power as to resist further division. These ultimate particles are called *atoms* or *molecules*, and it is by aggregation of these particles into a definite size and shape, that a *body* is constituted. Thus, in the forcible language of Locke, "the magnitude of the whole earth is from that of a mite." The intimate nature of matter is involved in mystery: the sum of our knowledge respecting it is limited to its sensible properties, some of which are essential to its existence, while others are only accidental or contingent. The former of these, which are generally termed the *physical*, as distinguished from the chemical, properties of matter, are Extension, Figure, Impenetrability, Divisibility, Inertia, Indestructibility, and Attraction.

2. *Extension.*—Extension is the property which bodies possess of occupying space, and relates to the qualities of length, breadth, and thickness, without which no substance can exist. Extension has no respect to the size or shape of

a body. A block of wood, of the dimensions of a square foot, may be divided into numerous smaller blocks, exactly resembling the large one in shape; these may again be divided until each block be reduced to the hundredth part of an inch in diameter; and each of these may be further subdivided, until they defy our power of measuring them; yet it is obvious that each little block will possess length, breadth, and thickness; in other words, each will possess the property of extension, as really as the original block, the only difference being that of dimension. It is, in fact, impossible to form a conception of matter, however minute the particle, without connecting with it the idea of its having a certain bulk, or filling a certain extent of space. This property of bodies is termed, in common language, *size* or *volume.*

3. *Figure.*—Figure or form is the result of Extension, for we cannot conceive that a body has length, breadth, and thickness, without its having some kind of figure, however irregular. Some solid bodies are found naturally under determinate forms, from which they never vary: a crystal of quartz has six sides, a garnet twelve sides. Other solids are so irregular, that they cannot be compared with any mathematical figure, as a fragment of a rock, or a chip of wood. Fluid bodies have no determinate form, but take their shapes from the vessels in which they are contained. The *volume* of a body has no relation to its figure: bodies which have the same figures may possess very different volumes; and bodies may have the same volume, under very different figures; thus, two masses of matter may present the same volume, although the one be round and the other square.

4. *Impenetrability.*—Impenetrability is the property by which one body occupies a certain space, to the exclusion of every other body from that space; or, in other words, by which two bodies cannot occupy the same space at the same time. 1. A nail, driven into a board or piece of lead, does not penetrate the wood or the metal; it merely *separates* and *displaces* the particles of these substances. 2. If a vessel be filled with water, and a stone, or any other substance heavier than water, be dropped into it, a quantity of the water, precisely equal to the bulk of the heavy body, will be displaced and flow over, affording a decisive proof that a body cannot enter the space occupied by another body, without previously ejecting the latter. 3. When salt is dissolved in water, neither of these substances is penetrated by the

other; the particles of the salt are merely separated from each other, and may again be obtained in their aggregate form. A similar phenomenon occurs when a piece of gold is dissolved in an acid. 4. Lastly, if a vessel be inverted in water or any other liquid, the impenetrability of the air prevents the ascent of the liquid within the vessel. This property of matter has been usefully and ingeniously applied in the construction and uses of the diving-bell.

5. *Divisibility.*—Divisibility is the property by which a body may be divided into minute parts. The division of matter, by mechanical means, is subject to limitation, but the extent to which it may be practically carried, almost exceeds credibility. 1. One grain of colouring matter will impart a tint to five pounds of pure water; and, as it is possible to render visible so small a quantity of water as a thousandth part of a grain, this minute portion of the mixture must contain a thirty-five millionth part of the grain of colouring matter. 2. A single grain of musk will diffuse a powerful odour through a spacious room, without losing any appreciable portion of its weight; the odour depends on the incessant radiation of particles of the musk, and the process will continue in activity for several years. 3. A grain of gold may be hammered so thin as to cover fifty square inches of surface, and present two millions of visible points; and the gold which covers the silver wire, employed in making gold lace, is spread over a surface twelve times as great. Wollaston made a gold wire of such extreme tenuity, that an ounce of it would extend fifty miles. 4. The film of soap and water, which constitutes the thinnest part of the soap-bubble, does not exceed in thickness the 2,500,000th part of an inch. 5. Microscopic investigations of organized matter furnish illustrations still more astonishing. Many of the animalcules which exist in water, are so minute in size, that an aggregation of millions of them would fall short of the bulk of a single grain of sand, while thousands might swim at the same time through the eye of the finest needle. These have circulating fluids; but what idea can we form of the minuteness of a globule of their blood, when we are informed that a single drop of human blood holds in suspension at least one million of these globules? 6. Lastly, the researches of Biot have shewn, that the thread by which the spider suspends herself from the web, is composed of more than 6000 single threads. The divisibility of matter, although mathematically illimitable,

is closely connected with its constitution, and must therefore cease with the ultimate molecules of which all matter is supposed to consist.

6. *Inertia.*—Inertia is the property by which matter is incapable of putting itself in motion, or of arresting its own progress, when put in motion by some force. 1. A ball rolled on the ground soon ceases to move, owing to the impediments it meets with from the roughness of the surface; if rolled on ice with the same force, its motion continues for a much longer period, the impediments being fewer; if projected into the air, its motion is arrested by gravity; but if projected into free space, where no impediments occur from air, friction, or gravity, it would exhibit the phenomenon of perpetual motion. 2. If a common top, with a small hard point, be set in motion in a vessel from which the air has been removed by means of an air-pump, it will continue to spin for several hours, because there is no air to resist its motion. 3. A pendulum, set in motion in a vessel similarly exhausted of air, will continue to swing without the aid of machinery for an entire day, the only impediments to its perpetual motion being the small amount of friction at the point of suspension, and gravity. 4. We have perpetual examples of inertia in the motions of the planetary bodies: the spaces through which they move being void of the obstacles of air and friction, their motions have continued the same during many thousands of years. 5. Familiar instances of inertia are found in the employment of locomotion. A considerable force is required at first to set a carriage in motion; but when this has been effected, it moves onward with comparative ease, so that, in fact, a considerable force becomes necessary to arrest its progress. If a passenger be standing in a carriage when suddenly put in motion, his feet, obeying the impulsion of the carriage, are drawn forward; his body, obeying the law of inertia, remains in its former position; he, consequently, falls backward. On the other hand, if the passenger be standing when the carriage is suddenly stopped, the opposite result will take place: his body has acquired an onward motion, imparted to it by that of the carriage, and the sudden stoppage of the latter throws him forward. 6. A trivial experiment will serve to illustrate the law of inertia. A card being poised on the top of the finger, and a coin placed on the card, the former may, by a dexterous horizontal fillip, be projected from its place, the latter remaining on the top of

the finger; in this case, the friction produced by the card is not sufficient to counteract the inertia of the coin.

7. *Indestructibility.*—Indestructibility is the property by which matter never ceases to exist. It may change its form, and disappear, but it is not annihilated. 1. Mercury, water, and other substances, may be converted into vapour, or distilled in close vessels, but they may be again condensed by the application of a cold body, and restored to their former condition, without the loss of a single particle. 2. Animals and vegetables die, and are decomposed, but their elementary particles immediately enter into new combinations, and furnish materials of nutriment for other animals and vegetables. The very refuse of matters which have served as food and clothing, which taint the air, and render it pestilential, may, when spread upon the surface of the soil, be the means of covering it with verdure, and endowing it with fertility. 3. In the following case of what is called, in the language of chemists, destructive distillation, it is evident that nothing is destroyed. When a piece of wood is heated in a close vessel, as a retort, we obtain water, an acid, several kinds of gas, and a black, porous substance, called charcoal. The wood is thus decomposed, and its particles take a new arrangement, and assume new forms; but that nothing is lost, is proved by the fact, that, if the water, acid, gases, and charcoal, be collected and weighed, they will be found exactly as heavy as the wood was before distillation.

8. *Attraction.*—Attraction is the property by which bodies tend towards each other. This property manifests itself in various ways, and has received specific designations according to the circumstances under which it acts. The several kinds of attraction are explained in the following paragraphs:—

9. *Attraction of Cohesion.*—It was ascertained by Newton that every particle of matter has a tendency to approach and unite itself to other particles. This kind of attraction operates at insensible distances, and consists in maintaining the constituent parts of a body in cohesion with each other, and in resisting their separation. The tendency of cohesion is powerfully counteracted by the operation of another law, a principle of *repulsion*, which prevents the approximation of the particles of matter. It is generally supposed that this repulsion is owing to the agency of heat, which is in some way connected with the elementary molecules; and that the

forms of bodies, as regards their solidity or fluidity, are determined by the relative intensities of these two antagonizing forces. Thus, when attraction predominates among the particles of a body, this body occurs in the *solid* state; when repulsion prevails, the body assumes a *gaseous* or aeriform condition; when neither of these forces is in excess, the *liquid* form is the result, and the particles of the body exhibit a free motion among themselves. A familiar illustration of these principles is afforded us in the substance which, by the addition or subtraction of heat, is capable of assuming the three forms of ice, of water, and of steam.

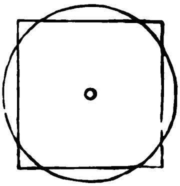
10. The attraction of cohesion, as it occurs in *solid* bodies, may be exemplified by the difficulty experienced in separating two substances with smooth surfaces, which have been pressed closely together. If two pieces of clean plate glass, or two discs of lead or brass, be brought into close union by a screw-like pressure, a considerable force will be required to separate them from each other; the effect will be much increased by interposing a little oil between the surfaces, in order to fill up any superficial inequalities. Two pieces of caoutchouc, if pressed together by freshly cut surfaces, will exhibit a force of cohesion which it is scarcely possible to counteract. This kind of attraction is much stronger in some bodies than in others: it is stronger in the metals than in most other substances, and in these bodies also, it varies in its intensity. Thus a small iron wire will hold a suspended weight of many pounds, without having its particles separated; the particles of water are divided by a very small force, while those of air are still more easily moved among themselves. These different properties depend upon the force of cohesion with which the several particles of these bodies are united.

11. "When the particles of *fluid* substances are left to arrange themselves according to the laws of attraction, the bodies which they compose assume the form of a globe or ball. Drops of water thrown on an oiled surface or on wax, globules of mercury, hail stones, a drop of water adhering to the end of the finger, tears running down the cheeks, and dew drops on the leaves of plants, are all examples of this law of attraction. The manufacture of shot is also a striking illustration of this law: the lead is melted and poured into a sieve, at the height of about two hundred feet from the ground; the stream of lead, immediately after leaving the sieve, separates into round globules, which, before they reach

the ground, are cooled and become solid, and thus are formed the shot used by sportsmen.

12. "To account for the globular form in all these cases, we have only to consider that the particles of matter are mutually attracted towards a common centre, and in liquids being free to move, they arrange themselves accordingly. In all figures, except the globe or ball, some of the particles must be nearer the centre than others. But in a body that is perfectly round, every part of the outside is exactly at the same distance from the centre. Thus, the corners of a cube, or square, are at much greater distances from the centre, than the sides, while the circumference of a circle or ball is every-where at the same distance from it. This difference is shown by fig. 1, and it is quite obvious, that if the particles of matter are equally attracted towards the common centre, and are free to arrange themselves, no other figure could possibly be formed, since then every part of the outside is equally attracted. The sun, earth, moon, and indeed all the heavenly bodies are illustrations of this law, and therefore were probably in so soft a state when first created, as to allow their particles freely to arrange themselves in their present forms."

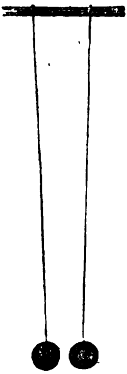
Fig. 1.



13. *Attraction of Gravitation.*—As the attraction of cohesion is the force by which the particles of a body are united into masses, so the attraction of gravitation is the force by which these masses tend toward each other; and as the former law operates at sensible, so the latter operates at insensible distances. The term gravitation does not here strictly refer to the weight of bodies, but to the attraction of the masses of matter towards each other, whether downwards, upwards, or horizontally. The attraction of gravitation is mutual, since all bodies not only attract other bodies, but are themselves attracted. 1. The sun attracts the earth at a distance of 95,000,000 miles; the earth attracts the moon at the distance of 240,000 miles; the moon reciprocally attracts the earth, the moveable parts of which, or the waters, under the influence of this attraction, exhibit the phenomena of tides. Upon this principle, Newton founded his law of universal gravitation. 2. Two cannon balls, when suspended by long

cords, so as to hang very near each other, are found to exert a mutual attraction, so that neither of the cords is exactly perpendicular, but each approaches the other, as represented in the adjoining figure. 3. In the same manner, the heavenly bodies, when they approach each other, are drawn out of the line of their paths, or orbits, by mutual attraction. 4. Lastly, the effect of gravitation, as it exists on the surface of our globe, is seen in the tendency which all bodies possess of descending in straight lines toward the centre of the earth; and the force which acts in separating a body from the surface of the earth, or in preventing it from descending to the surface, is called its *weight*.

Fig. 2.



14. "The force of attraction increases in proportion as bodies approach each other, and by the same law it must diminish in proportion as they recede from each other. Attraction, in technical language, is inversely as the squares of the distances between the two bodies: that is, in proportion as the square of the distance increases, in the same proportion attraction decreases. Thus, if at the distance of 2 feet, the attraction be equal to 4 pounds, at the distance of 4 feet, it will be only 1 pound; for the square of 2 is 4, and the square of 4 is 16, which is 4 times the square of 2. On the contrary, if the attraction at the distance of 6 feet be 3 pounds, at the distance of 2 feet it will be 9 times as much, or 27 pounds, because 36, the square of 6, is equal to 9 times 4, the square of 2." The gradual diminution of attraction, as the distance increases, is shown in the following table: in the upper line, the distance is expressed by progressive numbers; in the lower, the diminution of attraction is indicated in the corresponding departments by arithmetical fractions:—

Distance.	1	2	3	4	5	6	7	8	and so on.
Attraction.	1	$\frac{1}{4}$	$\frac{1}{9}$	$\frac{1}{16}$	$\frac{1}{25}$	$\frac{1}{36}$	$\frac{1}{49}$	$\frac{1}{64}$	and so on.

It is here shown that, at the distance of 8, the attractive force is diminished to a 64th part of what it was at 1.

"15. The force of the attraction of gravitation, is in proportion to the quantity of matter the attracting body contains. Some bodies of the same bulk contain a much greater quantity of matter than others: thus, a piece of lead contains about twelve times as much matter as a piece of cork of the same dimensions, and therefore a piece of lead of any given size, and a piece of cork twelve times as large, will attract each other equally.

16. *Capillary Attraction.*—" Capillary attraction is the force by which a liquid rises in small tubes, or porous substances, above its level. If a small glass tube be placed in water, the water on the inside will be raised above the level of that on the outside of the tube. The cause of this seems to be nothing more than the ordinary attraction of the particles of matter for each other. The sides of a small orifice are so near each other, as to attract the particles of the fluid on their opposite sides, and as all attraction is strongest in the direction of the greatest quantity of matter, the water is raised upwards, or in the direction of the length of the tube. On the outside of the tube, the opposite surfaces, it is obvious, cannot act on the same column of water, and therefore the influence of attraction is here hardly perceptible in raising the fluid. This seems to be the reason why the fluid rises higher on the inside than on the outside of the tube.

17. "A great variety of porous substances are capable of this kind of attraction. If a piece of sponge or a lump of sugar be so placed, that its lowest portion touches the water, the fluid will rise and diffuse itself through the whole mass. In the same manner, the wick of a lamp will carry up the oil to supply the flame, though the flame is several inches above the level of the oil. If the end of a towel happen to be left in a basin of water, it will empty the basin of its contents. And on the same principle, when a dry wedge of wood is driven into the crevice of a rock, and afterwards moistened with water, as when the rain falls upon it, it will absorb the water, swell, and sometimes split the rock. In Germany, millstone quarries are worked in this manner." Lastly, it is supposed that this kind of attraction is one of the causes of springs of water in the earth. The water rises through porous beds of sand, small stones, and crevices of rocks, and thus reaches surfaces of great elevation. The lower parts of the walls, and the earthen floors of cottages, are rendered constantly damp by the attraction of moisture upwards from the

ground; hence the necessity of removing all porous matters from the foundations of houses.

18. *Chemical Attraction.*—The forces of attraction, already described, are among the *physical* properties of matter. There are, however, other forces in nature, which belong more exclusively to the science of chemistry, and which, with reference to the materials of which our globe is composed, produce effects equal in importance and interest to any other. 1. If water be mixed with water, or salt with salt, the effect is merely an increase of *quantity;* no change of *quality* is produced. 2. If a blue and a yellow powder be mixed together, a green powder is produced; but this is merely an effect impressed upon the eye by the intimate *mixture* of the yellow and blue light which is separately reflected from the minute particles of each; these particles may be separated mechanically, and the powders restored to their former appearance. 3. If two coloured liquids, having no chemical attraction for each other, be mixed together, a liquid of a different colour is produced, and the two ingredients cannot, it is true, be mechanically separated; yet, even in this case, the liquid is a mere *mixture*, and its properties are accordingly intermediate between those of the liquids mixed. In these three cases there is no *change of property*, nor is any new property superadded; in other words, the substances being similar, no chemical attraction takes place. 4. But when potash, dissolved in water, is mixed with tartaric acid, also dissolved in water, a solid substance, called cream of tartar, is thrown down in the vessel; this substance is neither potash nor tartaric acid, nor can either of these ingredients be again procured from it; the liquid also from which it subsided, no longer presents the qualities of the ingredients which were mixed in it, but those of a *new* and entirely *different* substance. The potash and tartaric acid have, therefore, united with each other, to form a *chemical compound*, which, when carefully collected, is exactly of the same weight as the ingredients possessed before their union, but of entirely different qualities. This compound is formed by chemical attraction. By the operation of the same law, sulphur and mercury, when heated together, form a beautiful red compound, known under the name of *vermillion*, and which has none of the qualities of sulphur or of mercury.

19. Chemical attraction, therefore, is that force by which the particles of substances of different kinds unite together,

and form compounds. This species of attraction takes place only between the particles of certain substances, and is not, therefore, a universal property. It is also known under the name of *chemical affinity*, because it is said, that the particles of substances having an affinity between them, will unite, while those having no affinity for each other do not readily enter into union. There seem, indeed, in this respect, to be very singular preferences, and dislikes, existing among the particles of matter. 1. If a piece of marble be thrown into sulphuric acid, their particles will unite with great rapidity and commotion, and there will result a compound differing in all respects from the acid or the marble. But if a piece of glass, quartz, gold, or silver, be thrown into the acid, no change is produced on either, because their particles have no affinity. 2. Water combines readily with alcohol, feebly with ether, and scarcely at all with oil. 3. Sugar dissolves readily in water, sparingly in alcohol; while camphor dissolves freely in alcohol, and sparingly in water. 4. A rod of gold, plunged into a vessel of water, and then withdrawn, retains but little of the liquid on its surface, and this may be easily removed; but, on repeating the experiment with mercury, a coating of this metal adheres to the rod, and cannot be removed; the gold is rendered white, and, if the surface be scraped, the portions thus removed contain gold and mercury united by chemical attraction. 5. A piece of tin may be made to float on melted lead; but, as the tin melts, it becomes intimately united with the lead, and each particle of the compound, when solid, will be found to consist of both metals. In this case, the force of attraction counteracts that of gravitation. 6. The air inhaled in the act of respiration is different from that which is exhaled; on breathing through a tube into lime water, a combination takes place between the carbonic acid, an ingredient of the exhaled air, and the lime, and a white substance, chalk, is formed in the liquid.

20. "Again: oil and water have no affinity for each other, but potash has an attraction for both, and therefore oil and water will unite when potash is mixed with them. In this manner, the well-known article called *soap* is formed. But the potash has a stronger attraction for an acid than it has for either the oil or the water; and therefore when soap is mixed with an acid, the potash leaves the oil, and unites with the acid, thus destroying the old compound, and at the same instant forming a new one. The same happens when soap is dis-

solved in any water containing an acid, as the water of the sea, and of certain wells. The potash forsakes the oil, and unites with the acid, thus leaving the oil to rise to the surface of the water. Such waters are called *hard*, and will not wash, because the acid renders the potash a neutral substance."

21. The following illustrations may be adduced of the change of properties induced by chemical combinations:—1. Water, a liquid, consists of two gases, hydrogen and oxygen, neither of which has ever been compressed into a liquid; hydrogen is one of the most inflammable bodies in nature, but water cannot be inflamed; oxygen supports combustion with great brilliancy, but water extinguishes combustion, 2. *Common salt*, which is not only harmless, but absolutely necessary for man, consists of two formidable ingredients, viz. the metal sodium, and the gas chlorine; either of which taken into the stomach is fatal to life. When presented to each other, they burst into flame, and instantly lose their dangerous properties. 3. *Glauber's salt*, a valuable medicine, is composed of two caustic poisonous substances, viz. oil of vitriol, and barilla or soda. 4. The *Atmosphere* we breathe is composed of the same ingredients as that most violent and destructive liquid called aqua fortis, or nitric acid. 5. *Charcoal* is a solid substance which has never been reduced to a state of vapour; and the diamond, which is merely crystallized charcoal, is one of the hardest bodies in nature. *Sulphur*, in its simple state, is a solid substance, and requires a high temperature to maintain it in a state of vapour. But when carbon, the pure principle of charcoal, and sulphur are made to combine, the compound, instead of being solid, is a thin liquid, and cannot be frozen or rendered solid at any temperature; and instead of being difficult to vaporize, is one of the most evaporable of all liquids. 6. *Copper* is a soft metal; *tin* is a still softer; but the compound is exceedingly hard. 7. Numerous examples of changes of properties occur in the combination of acids with alkalies. *Sulphuric acid*, for instance, and *soda*, possess caustic properties; the former is intensely acid, and converts the blue colour of vegetables into red; the latter has a pungent taste, and turns the blue colour of vegetables into green; on causing the two substances to combine, these properties of each are lost, and no effect is produced by the compound on vegetable colours; they appear to have neutralized each other's properties.

22. "*Magnetic Attraction.*—There is a certain ore of iron,

a piece of which, being suspended by a thread, will always turn one of its sides to the north. This is called the *loadstone*, or *natural magnet*, and when it is brought near a piece of iron, or steel, a mutual attraction takes place, and under certain circumstances, the two bodies will come together and adhere to each other. This is called *magnetic attraction*. When a piece of steel or iron is rubbed with a magnet, the same virtue is communicated to the steel, and it will attract other pieces of steel, and if suspended by a string, one of its ends will constantly point towards the north, while the other, of course, points towards the south. This is called an *artificial magnet*. The *magnetic needle* is a piece of steel, first touched with the loadstone, and then suspended, so as to turn easily on a point. By means of this instrument, the mariner guides his ship through the pathless ocean." *See Magnetism.*

23. *Electrical Attraction.*—When a piece of glass, or sealing-wax, is rubbed with the dry hand, or a piece of cloth, and then held towards any light substance, as a hair, a thread, or a pith-ball, the light body will be attracted by it, and will adhere for a moment to the glass or wax. The force which thus moves the light body is called *electrical attraction*. When the light body has adhered to the surface of the glass or sealing-wax for a moment, it is repelled or thrown off again, by what is called *electrical repulsion*. *See Electricity.*

24. In addition to the universal and inherent properties of matter above described, there are several other qualities, which are peculiar to certain bodies, and in different degrees; or peculiar to some bodies, without affecting others in the slightest degree. These are density and rarity; hardness and elasticity; brittleness, malleability, ductility, tenacity, and crystalline texture.

25. *Density and Rarity.*—The quality of density relates to the compactness of bodies, or the number of particles, which a body contains within a given bulk; in other words, it denotes closeness of texture. Bodies, which are most dense, are those which contain the least number of pores. Hence the most dense substances in nature are found among the metals; gold, for instance, is upwards of 19 times, and platinum nearly 21 times, heavier than an equal bulk of water. But density is not an essential character of metals: potassium and sodium are so light as to float upon the surface of water. Two bodies being of the same bulk, that which weighs more than the other, is the more dense. Some metals become

denser on being hammered, their particles being brought together permanently by this operation. The density of air is increased by forcing more into a close vessel than it naturally contains.

26. *Rarity* is the quality opposed to density, and denotes that the substance to which it is applied is porous and light: the intervals between the particles of matter are augmented, and hence the same number of particles occupy a larger space. The term is chiefly applied to aeriform bodies, the terms *dilatation* and *expansion* being employed in speaking of solids and liquids. In the free atmosphere, rarefaction is promoted by diminishing the pressure, and the pressure is diminished with the elevation, the upper strata being always more rarefied and expanded than the lower strata upon which they press. Thus, at an elevation of 2.705 miles from the surface of the sea, the atmosphere loses half its density, or one volume is expanded into two volumes; the density is again halved for every 2.7 miles of additional elevation. The limits to which rarefaction may be carried, are not known; but it has been proved by experiments with the air-pump, that air may be rarefied so as to occupy a volume 13,000 times greater than it occupies under the ordinary pressure.

27. *Hardness and Elasticity.*—The quality of hardness is not in proportion, as might be expected, to the density of the substance, but to the force with which the particles of a body cohere, or keep their places. Glass, for instance, will scratch gold or platinum, though these metals are much more dense than glass. It is probable, therefore, that these metals contain the greatest number of particles, but that those of glass are more firmly fixed in their places. The relative hardness of the metals among themselves has not been determined. Among the hardest are placed iron, zinc, copper, manganese, nickel, titanium, and palladium; gold, silver, platinum, are of a softer quality; lead is still softer than these; and potassium and sodium are so soft as to yield to pressure of the finger. Some of the metals are capable of being rendered hard or soft at pleasure: thus, steel, when heated, and then suddenly cooled, becomes harder than glass, while, if allowed to cool slowly, it is soft and flexible.

28. *Elasticity* is the quality by which bodies, after being forcibly compressed or bent, regain their original state when the force is removed. Some substances are highly elastic,

while in others this quality is entirely absent. The separation of two bodies, after collision, is a proof that one or both are elastic. The quality of elasticity is connected with that of hardness, the hardest bodies being also the most elastic. Ivory, glass, marble, flint, and ice, are elastic solids: an ivory ball dropped upon a marble slab, will bound to a height nearly equal to that from which it fell, and no mark will be left on either substance. India rubber is exceedingly elastic, and, on being projected forcibly against a hard body, will bound to a considerable distance. Certain substances, as putty, dough, and wet clay, are entirely devoid of elasticity, and, when projected against a hard body, they become flattened, adhere to the body, and never reassume their former shape. Among fluids, water, oil, and liquid substances in general, are nearly inelastic, while air and gaseous fluids are the most elastic of all bodies.

29. The *sonorous* quality of metals is allied to their hardness and elasticity. If three bells be cast from the same mould, one of copper nearly pure, the second of good tin, and the third of a mixture of both; the first will have a dull heavy sound, the second scarcely any sound at all, while the third will have a clear musical sound. Hence, bell-metal is a compound of tin and copper.

30. *Brittleness.*—This quality denotes that the bodies to which it belongs admit of being easily broken, or separated into irregular fragments; and it is found chiefly in hard bodies. It does not appear that brittleness is entirely opposed to elasticity, since, in many substances, these qualities are united. Glass is the standard or type of brittleness, and yet a ball, or fine threads of this substance, are highly elastic, as may be seen by the bounding of the one, and the springing of the other. Brittleness often results from the treatment to which substances are submitted. Iron, steel, brass, and copper, become brittle when heated and suddenly cooled; but, if cooled slowly, they do not admit of being easily broken.

31. *Malleability.*—Malleability is the quality by which some metals admit of being extended into thin plates or leaves under the hammer, or rolling-press; its employment is of great importance in the arts and conveniences of life. This quality depends upon a high degree of *tenacity* connected with a certain degree of *softness.* The malleable metals are gold, silver, iron, copper, and some others. Of these, gold

is the most malleable: a grain of gold may be extended so as to cover 50 square inches of surface, and to have a thickness not exceeding 1-282,020th of an inch; it may thus present two millions of visible points, and admit of the transmission of light through its substance. Zinc is malleable in the highest degree between the temperatures of 300° and 400°; and iron at a temperature exceeding that of a red heat. Some metals are very slightly malleable, or, like antimony, arsenic, bismuth, and cobalt, actually brittle. Metals which have become brittle, either in consequence of fusion, or of long continued hammering, are again rendered malleable by *annealing*, or the process of heating a metallic body, and allowing it to cool in a moderate temperature. A few of the malleable metals can be *welded*, or portions of them joined together by hammering. Iron and platinum may be welded together at a bright-red heat, and fragments of potassium may be made to adhere by pressing them together by the hand at the ordinary temperature of the air.

32. *Ductility.*—Ductility is the quality by which a metal admits of being drawn out into wire. Wollaston succeeded in drawing platinum into threads not much larger than those of the spider's web; he also formed a gold wire so thin as to be only 1-5000th of an inch in diameter: 550 feet of it weighed only one grain; an ounce of it would extend 50 miles. We might expect that the most malleable metals would be also the most ductile; but experiment proves that this is not the case. The ductility of metals is not always proportional to their malleability; iron, for instance, may be drawn into very fine wire, but it cannot be beaten into very thin leaves; on the other hand, tin and lead may be hammered into thin leaves, but cannot be drawn into small wire.

33. *Tenacity.*—Tenacity is the quality by which a body resists extension or the separation of its parts; it is a direct result of the attractive force of cohesion among the particles of a solid, and may be employed as a measure of the intensity of this form of attraction. There is a considerable difference in the tenacity of different substances; some possess this quality in a remarkable degree, while others are torn asunder by the smallest force. 1. Every thing prepared from flax and hemp, is composed of woody tissue, which possesses great tenacity and strength, and is hence employed in the manufacture of linen; whilst cotton is composed of cellular tissue, which is brittle, and possesses little or no cohe-

sion among its particles. Alphonse De Candolle gives the following as the result obtained by Labillardière, as to the relative strength of different organic fibres. He found that, on suspending weights to threads of the same diameter,

Silk supported a weight equal to . . .	34
New Zealand flax	23⅕
Hemp	16⅓
Flax	11¾
Pita flax (Agave Americana)	7

2. The tenacity of different metals is determined by ascertaining the weight which a wire of a certain thickness can support without breaking. This quality appears to be highest in iron, and lowest in lead. The tenacity of different metals is shown in the following table, in which the diameter of each wire is the 0.787th of a line:—

Iron wire supports a weight of	549·25lbs.
Copper	302·278
Platinum	274·32
Silver	187·137
Gold	150·753
Zinc	109·54
Tin	34·63
Lead	27·621

It has been found that the tenacity of wires of iron, copper, and brass, is much impaired by *annealing* them.

34. *Crystalline Texture.*—When bodies pass from the liquid or gaseous into the solid state, their particles often cohere into irregular, unsymmetrical masses. But, more generally, the particles cohere in a regular, symmetrical form. Such bodies are termed *crystals*, and the process by which they are formed, is called *crystallization*. 1. Water, as it freezes, assumes various symmetrical forms, shooting into spiculæ, &c., as may be seen on a window in frosty weather. 2. If a quantity of sugar be dissolved in water, and the solution be allowed to evaporate, the sugar again becomes solid; but, in resuming its solidity, it assumes a particular form of great regularity,—it is now a transparent six-sided prism. 3. If a wire basket be suspended in a strong solution of alum, or sulphate of copper, and withdrawn in an hour or two, it will be found to be covered with a crust of beautifully formed crystals. 4. If half an ounce of the sulphates of magnesia, of soda, of copper, and half an ounce of alum, be mixed together in boiling water, and allowed to

evaporate, each salt will be found to crystallize separately, having the same form and properties which it possessed previously to its solution.

35. Many of the metals are capable of assuming crystalline forms, which are, generally, those of the *cube* and the *octohedron*. The facility of procuring metallic crystals is proportionate to the lowness of the temperature at which a metal fuses: bismuth conducts heat less perfectly than other metals, and therefore yields crystals most readily. The texture of iron is *fibrous;* that of zinc, bismuth, and antimony, *lamellated*, or in minute plates.

36. Certain bodies, when treated in different ways, afford two varieties of crystals, the primary forms of which are incompatible with each other. Sulphur is one of these bodies: in passing from a state of *fusion* to a high temperature, its form is a secondary modification of an oblique prism with a rhomboidal base; but, after being *dissolved* in sulphuret of carbon at a lower temperature, it is deposited in the form of an elongated octohedron with a rhomboidal base; the latter is the form of crystal found in native sulphur and in the flowers of sulphur. Bodies of this kind are termed *dimorphous*, from δις. twice, and μορφὴ, form.

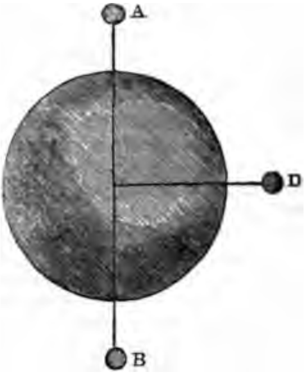
37. The universal properties of matter, and the peculiar qualities of certain bodies, having been explained, the further consideration of the subject relates to the laws and phenomena of *Force* and *Motion*, as exhibited by matter possessing these properties and qualities.

PHENOMENA OF GRAVITATION.

38. *Terrestrial Gravitation.*—It has already been stated, § 13, that the force by which bodies, in masses, are drawn towards each other, is termed the attraction of gravitation. The attraction which the earth exerts on all bodies near its surface, is called *terrestrial gravitation*, and the specific force with which any body is attracted, is termed its *weight*. All falling bodies tend towards the centre of the earth, in right lines; or, to speak more strictly, with reference to the spheroidal figure of the earth, in lines perpendicular to the surface of still water. It follows, therefore, that two falling bodies, on opposite parts of the earth, mutually fall towards each other; and, upon the same principle, that a body falling at the distance of a quarter, instead of that of a half, of the earth's circumference from us, is carried in a direction exactly

across, or at right angles to, the line above indicated. "This will be readily understood by fig. 3, where the circle is supposed to be the circumference of the earth; A, the ball falling towards its upper surface, where we stand; B, a ball falling towards the opposite side of the earth, but ascending in respect to us; and D, a ball descending at the distance of a quarter of the circle, from the other two, and crossing the line of their direction at right angles. It will be obvious, therefore, that what we call *up* and *down* are merely relative terms, and that what is *down* in respect to us, is *up* in respect to those who live on the opposite side of the earth, and so the contrary. Consequently, *down* everywhere means towards the centre of the earth, and *up* from the centre of the earth; because all bodies descend towards the earth's centre, from whatever part they are let fall. This will be apparent when we consider, that as the earth revolves on its axis every 24 hours, we are carried with it through the points A, D, and B; and therefore, if a ball is supposed to fall from the point A, at 12 o'clock, and the same ball to fall again from the same point above the earth at 6 o'clock, the two lines of direction will be at right angles, as represented in the figure, for that part of the earth which was under A at 12 o'clock, will be under D at 6 o'clock, the earth having in that time performed one quarter of its daily revolution. At 12 o'clock at night, if the ball be supposed to fall again, its line of direction will be at right angles with that of its last descent, and consequently it will *ascend* in respect to the point on which it fell 12 hours before, because the earth would have then gone through one half her daily rotation, and the point A would be at B.

Fig. 3.



39. *Velocity of Falling Bodies.*—"The velocity or rapidity of every falling body, is uniformly accelerated, or increased,

in its approach towards the earth, from whatever height it falls. 1. If a rock is rolled from a steep mountain, its motion is at first slow and gentle, but as it proceeds downward, it moves with perpetually increased velocity, seeming to gather fresh speed every moment, until its force is such that every obstacle is overcome; trees and rocks are beat from its path, and its motion does not cease until it has rolled to a great distance on the plain. 2. The same principle of increased velocity as bodies descend from a height, is curiously illustrated by pouring molasses or thick syrup from an elevation to the ground. The bulky stream, of perhaps two inches in diameter, where it leaves the vessel, as it descends, is reduced to the size of a straw, or knitting needle; but what it wants in bulk is made up in velocity, for the small stream at the ground, will fill a vessel just as soon as the large one at the outlet. 3. For the same reason, a man may leap from a chair without danger, but if he jumps from the house top, his velocity becomes so much increased, before he reaches the ground, as to endanger his life by the blow.

40. "It is found by experiment, that the motion of a falling body is increased, or accelerated, in regular mathematical proportions. These increased proportions do not depend on the increased weight of the body, because it approaches nearer the centre of the earth, but on the constant operation of the force of gravity, which perpetually gives new impulses to the falling body, and increases its velocity. It has been ascertained by experiment, that a body, falling freely, and without resistance, passes through a space of 16 feet and 1 inch during the first second of time. Leaving out the inch, which is not necessary for our present purpose, the ratio of descent is as follows:—If the height through which a body falls in one second of time be known, the height which it falls in a proposed time may be computed. For since the height is proportional to the square of the time, the height through which it will fall in *two* seconds will be *four* times that which it falls through in *one* second; in *three* seconds it will fall through *nine* times that space; in *four* seconds, *sixteen* times that of the first second; in *five* seconds, *twenty-five* times, and so on in this proportion."

41. The law of gravitation may, therefore, be succinctly stated in the following formula:—The gravitating forces of bodies are to each other, *directly as their masses*, and *inversely as the squares of their distances.* Thus, if the mass of one

body be 2, 3, 4, or five times greater than the mass of another body, its gravity is also 2, 3, 4, or 5 times *greater;* and if the distance be 2, 3, 4, or 5 times greater, the force of gravity is respectively 4, 9, 16, or 25 times *less*. A simple application of this law will be found in the following *rule*:—

"Reduce the given time to seconds; take the square of the number of seconds in the time, and multiply the height through which the body falls in one second by that number, and the result will be the height sought. The following table exhibits the height and corresponding times as far as 10 seconds:—

Time.	1	2	3	4	5	6	7	8	9	10
Height.	1	4	9	16	25	36	49	64	81	100

Each unit in the upper row expresses a second of time, and each unit in those of the second row expresses the height through which a body falls freely in a second. Now, as the body falls at the rate of 16 feet during the first second, this number, according to the rule, multiplied by the square of the time—that is, by the numbers expressed in the second line, will show the actual distance through which the body falls.

"Thus we have for the *first* second, . . 16 feet.
For the end of the *second*, 4 × 16 = 64 —
" third, 9 × 16 = 144 —
" fourth, 16 × 16 = 256 —
" fifth, 25 × 16 = 400 —
" sixth, 36 × 16 = 576 —
" seventh, 49 × 16 = 784 —
and for the 10 seconds, ... 1600 —

42. "If, on dropping a stone from a precipice, or into a well, we count the seconds from the instant of letting it fall, until we hear it strike, we may readily estimate the height of the precipice, or the depth of the well. Thus, suppose it is 5 seconds in falling, then we have only to square the seconds, and multiply this by the distance the body falls in one second. We have then 5 × 5 = 25, the square, which 25 × 16 = 400 feet, the depth of the well. Thus it appears that, to ascertain the velocity with which a body falls in any given time, we must know how many feet it fell during the first second; the

velocity acquired in one second, and the space fallen through during the time, being the fundamental elements of the whole calculation, and all that are necessary for the computation of the various circumstances of falling bodies. The difficulty of calculating exactly the velocity of a falling body from an actual measurement of its height, and the time which it takes to reach the ground, is so great, that no accurate computation could be made from such an experiment.

43. *Atwood's Machine.*—“This difficulty has, however, been overcome by a curious piece of machinery, invented for this purpose by Mr Atwood. This machine consists of an upright pillar, as shown in the figure. The weights A and B are of the same size, and made to balance each other very exactly, and are connected by the thread which passes over the wheel. R is a ring through which the weight A passes, and S is a stage on which the weight rests in its descent. The ring and stage both slide up and down, and are fixed at pleasure by thumb screws. The pillar is a graduated scale, and M is a small bent bar of metal, weighing a quarter of an ounce, and longer than the diameter of the ring R. When the machine is to be used, the weight A is drawn up to the top of the scale, and the ring and stage are placed a certain number of inches from each other. The small bar M is then placed across the weight A, by means of which it is made slowly to descend. When it has descended to the ring, the small weight M is taken off by the ring, and thus the two weights are left equal to each other. Now it must be observed, that the motion, and descent of the weight A is entirely

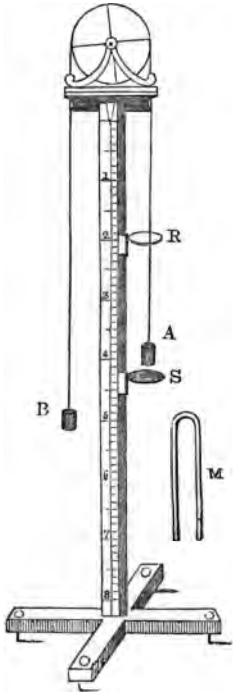


Fig. 4.

owing to the gravitating force of the weight M, until it arrives at the ring R, when the action of gravity is suspended, and the large weight continues to move downwards to the stage, in consequence of the velocity it had acquired previously to that time.

44. "To comprehend the accuracy of this machine, it must be understood that the velocities of gravitating bodies are supposed to be equal, whether they are large or small, this being the case when no calculation is made for the resistance of the air. Consequently, the weight of a quarter of an ounce placed on the large weight A, is a representative of all other solid descending bodies. The slowness of its descent, when compared with freely gravitating bodies, is only a convenience by which its motion can be accurately measured, for it is the *increase* of velocity which the machine is designed to ascertain, and not the *actual* velocity of falling bodies. Now it will be readily comprehended, that in this respect, it makes no difference how slowly a body falls, *provided it follows the same laws as other descending bodies*, and it has already been stated, that all estimates on this subject are made from the known distance a body descends during the first second of time. It follows, therefore, that if it can be ascertained exactly how much faster a body falls during the third, fourth, or fifth second, than it did during the first second, by knowing how far it fell during the first second, we should be able to estimate the distance it would fall during all succeeding seconds. If, then, by means of a pendulum beating seconds, the weight A should be found to descend a certain number of inches during the first second, and another certain number during the next second, and so on, the ratio of increased descent would be precisely ascertained, and could be easily applied to the falling of other bodies; and this is the use to which this instrument is applied.

45. "By this machine it can also be ascertained how much the actual velocity of a falling body depends on the force of gravity, and how much on acquired velocity, for the force of gravity gives motion to the descending weight only until it arrives at the ring, after which the motion is continued by the velocity it had before acquired.

46. "From experiments accurately made with this machine, it has been fully established, that if the time of a falling body be divided into equal parts, say into seconds, the spaces through which it falls in each second, taken separately,

will be as the odd numbers 1, 3, 5, 7, 9, and so on, as already stated. To make this plain, suppose the times occupied by the falling body to be 1, 2, 3, and 4 seconds; then the spaces fallen through will be as the squares of these seconds, or times, viz. 1, 4, 9, and 16, the square of 1 being 1, the square of 2 being 4, the square of 3, 9, and so on. The distance fallen through, therefore, during the second second, may be found, by taking 1, the distance corresponding to 1 second, from 4, the distance corresponding to 2 seconds, and is therefore 3. For the third second, take 4 from 9, and therefore the distance will be 5. For the fourth second, take 9 from 16, and the distance will be 7, and so on. During the first second, then, the body falls a certain distance; during the next second, it falls three times that distance; during the third, five times that distance; during the fourth, seven times that distance, and so continually in that proportion.

47 "It will be readily conceived, that solid bodies falling from great heights, must ultimately acquire an amazing velocity by this proportion of increase. An ounce ball of lead, let fall from a certain height towards the earth, would thus acquire a force ten or twenty times as great as when shot out of a rifle. By actual calculation, it has been found that were the moon to lose her projectile force, which counterbalances the earth's attraction, she would fall to the earth in four days and twenty hours, a distance of 240,000 miles. And were the earth's projectile force destroyed, it would fall to the sun in sixty-four days and ten hours, a distance of 95,000,000 of miles.

48. "Every one knows by his own experience the different effects of the same body falling from a great or a small height. A boy will toss up his leaden bullet and catch it with his hand, but he soon learns, by its painful effects, not to throw it too high. The effects of hailstones on window-glass, animals, and vegetation, are often surprising, and sometimes calamitous illustrations of the velocity of falling bodies.

49. "It has been already stated that the velocities of solid bodies falling from a given height, towards the earth, are equal, or in other words, that an ounce ball of lead will descend in the same time as a pound ball of lead. This is true in theory, but there is a slight difference in this respect in favour of the velocity of the larger body, owing to the resistance of the atmosphere. We, however, shall at present consider all solids of whatever size, as descending through the same spaces in

the same times, this being exactly true when they pass without resistance. To comprehend the reason of this we have only to consider, that the attraction of gravitation in acting on a mass of matter acts on every particle it contains; and thus every particle is drawn down equally and with the same force. The effect of gravity, therefore, is in exact proportion to the quantity of matter the mass contains, and not in proportion to its bulk. A ball of lead of a foot in diameter, and one of wood of the same diameter, are obviously of the same bulk; but the lead will contain twelve particles of matter where the wood contains one, and consequently will be attracted with twelve times the force, and therefore will weigh twelve times as much.

50. *Attraction proportionable to the matter.*—"1. If, then, bodies attract each other in proportion to the quantities of matter they contain, it follows that if the mass of the earth were doubled, the weights of all bodies on its surface would also be doubled; and if its quantity of matter were tripled, all bodies would weigh three times as much as they do at present. 2. It follows also, that two attracting bodies, when free to move, must approach each other mutually. If the two bodies contain like quantities of matter, their approach will be equally rapid, and they will move equal distances towards each other. But if the one be small and the other large, the small one will approach the other with a rapidity proportioned to the less quantity of matter it contains. 3. It is easy to conceive, that if a man in one boat pulls at a rope attached to another boat, the two boats, if of the same size, will move towards each other at the same rate; but if the one be large and the other small, the rapidity with which each moves will be in proportion to its size, the large one moving with as much less velocity as its size is greater. 4. A man in a boat pulling a rope attached to a ship, seems only to move the boat, but that he really moves the ship is certain, when it is considered, that a thousand boats pulling in the same manner would make the ship meet them half-way. 5. It appears, therefore, that an equal force acting on bodies containing different quantities of matter, move them with different velocities, and that these velocities are in an inverse proportion to their quantities of matter.

51. "In respect to *equal forces*, it is obvious that in the case of the ship and single boat, they were moved towards

each other by the same force, that is, the force of a man pulling by a rope. The same principle holds in respect to attraction, for all bodies attract each other equally, according to the quantities of matter they contain, and since all attraction is mutual, no body attracts another with a greater force than that by which it is attracted. Suppose a body to be placed at a distance from the earth, weighing two hundred pounds; the earth would then attract the body with a force equal to two hundred pounds, and the body would attract the earth with an equal force, otherwise their attraction would not be equal and mutual. Another body weighing ten pounds, would be attracted with a force equal to ten pounds, and so of all bodies according to the quantity of matter they contain; each body being attracted by the earth with a force equal to its own weight, and attracting the earth with an equal force. If, for example, two boats connected by a rope, and a man in one of them pulls with a force equal to 100 pounds, it is plain that the force on each vessel would be 100 pounds. For, if the rope were thrown over a pulley, and a man were to pull at one end with a force of 100 pounds, it is plain it would take 100 pounds at the other end to balance them.

52. *Attracting bodies approach each other.*—"It is inferred from these principles, that all attracting bodies which are free to move, mutually approach each other, and therefore that the earth moves towards every body which is raised from its surface, with a velocity, and to a distance proportional to the quantity of matter thus elevated from its surface. But the velocity of the earth being as many times less than that of the falling body as its mass is greater, it follows that its motion is not perceptible to us.

53. "The following calculation will show what an immense mass of matter it would take to disturb the earth's gravity in a perceptible manner. If a ball of earth equal in diameter to the tenth part of a mile, were placed at the distance of the tenth part of a mile from the earth's surface, the attracting powers of the two bodies would be in the ratio of about 512 millions of millions to one. For the earth's diameter being about 8000 miles, the two bodies would bear to each other about this proportion. Consequently if the tenth part of a mile were divided into 512 millions of millions of equal parts, one of these parts would be nearly the space through which the earth would move towards the falling body. Now in the tenth part of a mile there are about 6400 inches, consequently

this number must be divided into 512 millions of millions of parts, which would give the eighty thousand millionth part of an inch through which the earth would move to meet a body of the tenth part of a mile in diameter.

ASCENT OF BODIES.

54. "Having now explained and illustrated the influence of gravity on bodies moving downward and horizontally, it remains to show how matter is influenced by the same power when bodies are moved upward, or contrary to the force of gravity. What has been stated in respect to the velocity of falling bodies is exactly reversed in respect to those which are thrown upwards, for as the motion of a falling body is increased by the action of gravity, so is it retarded by the same force, when thrown upwards. A bullet shot upwards, every instant loses a part of its velocity, until having arrived at the highest point from whence it was thrown, it then returns again to the earth.

55. "The same law that governs a descending body, governs an ascending one, only that their motions are reversed.

56. "The same ratio is observed to whatever distance the ball is propelled, or as the height to which it is thrown may be estimated from the space it passes through during the first second, so its returning velocity is in a like ratio to the height to which it was sent. This will be understood by Fig. 5. Suppose a ball to be propelled from the point A, with a force which would carry it to the point B in the first second, to C in the next, and to D in the third second. It would then remain nearly stationary for an instant, and in returning, would pass through exactly the same spaces in the same times, only that its direction would be reversed. Thus it will fall from D to C in the first second, to B in the next, and to A in the third. Now the force of a moving body is as its velocity and its quantity of matter, and hence the same ball will fall with exactly the same force that it rises. For instance, a ball shot out of a rifle, with a force sufficient to overcome a certain impediment, on returning, would again overcome the same impediment."

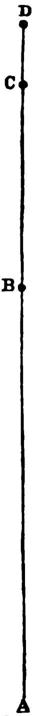


Fig. 5.

FALL OF LIGHT BODIES.

57. "It has been stated that the earth's attraction acts equally on all bodies, containing equal quantities of matter, and that in vacuo, all bodies, whether large or small, descend from the same heights in the same time. There is, however, a great difference in the quantities of matter which bodies of the same bulk contain, and consequently a difference in the resistance which they meet with in passing through the air. Now, the fall of a body containing a large quantity of matter in a small bulk, meets with little comparative resistance, while the fall of another, containing the same quantity of matter, but of larger size, meets with more in comparison, for it is easy to see that two bodies of the same size meet with exactly the same actual resistance. Thus, if we let fall a ball of lead, and another of cork, of two inches in diameter each, the lead will reach the ground before the cork, because, though meeting with the same resistance, the lead has the greater power of overcoming it.

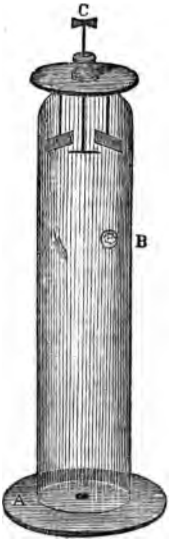


Fig. 6.

58. "This, however, does not affect the truth of the general law already established, that the weights of bodies are as the quantities of matter they contain. It only shows that the pressure of the atmosphere prevents bulky and porous substances from falling with the same velocity with such as are compact or dense. Were the atmosphere removed, all bodies, whether light or heavy, large or small, would descend with the same velocity. This fact has been ascertained by experiment in the following manner:

59. "The *air-pump* is an instrument by means of which the air can be pumped out of a close vessel, as will be seen under the article Pneumatics. Taking this for granted, at present, the experiment is made in the following manner:—

60. "On the plate of the air-pump A, place the tall jar B, which is open at the bottom, and has a brass cover fitted

closely to the top. Through the cover let a wire pass, air tight, having a small cross at the lower end. On each side of this cross, place a little stage, and so contrive them that by turning the wire by the handle C, these stages shall be upset. On one of the stages place a guinea or any other heavy body, and on the other place a feather. When this is arranged, let the air be exhausted from the jar by the pump, and then turn the handle C, so that the guinea and feather may fall from their places, and it will be found that they will both strike the plate at the same instant. Thus is it demonstrated, that were it not for the resistance of the atmosphere, a bag of feathers and one of guineas would fall from a given height with the same velocity and in the same time.

OF MOTION IN GENERAL.

61. *Laws of Motion.*—By the term *motion* is signified a continued change of place in bodies, with reference to a fixed point; and, according to the explanation, already given, of the universal property of matter, called *inertia* (§ 6.), the condition of motion is as natural to bodies as that of *rest*, or the opposite condition. Owing to the absence of volition, and the presence of inertia, every substance in nature presents a passive character, yielding itself to the operation of external causes, and wholly incapable of originating motion in itself, or of arresting any motion which may have been imparted to it. These and other fundamental laws of nature, in relation to rest and motion of matter, were announced by Newton in the three following propositions:—

1. Every body must persevere in its state of rest, or of uniform motion in a straight line, unless it be compelled to change that state by forces impressed upon it.
2. Every change of motion must be proportional to the impressed force, and must be in the direction of that straight line in which the force is impressed.
3. Action must always be equal and contrary to re-action; or the actions of two bodies upon each other must be equal, and their directions must be opposite.

Hence, in the language of philosophy, the power which communicates motion to a body, is called *force*. It is the force of gravity counteracting inertia, which determines the fall of a body towards the earth. The loaded waggon is set in motion by the muscular force of horses, the mill-wheel by the force of falling water, the vane by the force of wind; the motion of the steam-engine, and of various other machines, is maintained and regulated by the application of a fly-wheel. Without force, there could be no motion; without motion, there could be no rising or setting of the sun, no change of seasons, no fall of rain, no animal life.

62. *Absolute and Relative Motion.*—"For the sake of convenience and accuracy in the application of terms, motion is divided into two kinds, viz. absolute and relative. 1. *Absolute motion* is a change of place in a body with regard to a fixed point, and is estimated without reference to the motion of any other body. When a man rides along the street, or when a vessel sails through the water, they are both in absolute motion. 2. *Relative motion* is a change of place in a body, with respect to another body also in motion, and is estimated from that other body, exactly as absolute motion is from a fixed point. 3. The *absolute* velocity of the earth in its orbit from west to east, is 68,000 miles in an hour; that of Mars, in the same direction, is 55,000 miles per hour. The earth's *relative* velocity, in this case, is 13,000 miles per hour from west to east; that of Mars, comparatively, is 13,000 miles from east to west, because the earth leaves Mars that distance behind her, as she would leave a fixed point.

63. "*Rest*, in the common meaning of the term, is the opposite of motion; but it is obvious that rest is often a relative term, since an object may be perfectly at rest with respect to some things, and in rapid motion in respect to others. Thus a man sitting on the deck of a steam-boat, may move at the rate of fifteen miles an hour, with respect to the land, and still be at rest with respect to the boat. And so, if another man was running on the deck of the same boat at the rate of fifteen miles the hour in a contrary direction, he would be stationary in respect to a fixed point, and still be running with all his might with respect to the boat.

VELOCITY OF MOTION.

64. "Velocity is the rate of motion at which a body moves from one place to another, [and is estimated by comparing the distance with the time occupied in passing over it]. Velocity is independent of the weight or magnitude of the moving body—thus, a cannon-ball and a musket-ball, both flying at the rate of a thousand feet in a second, have the same velocities. 1. Velocity is said to be *uniform*, when the moving body passes over equal spaces in equal times: if a

steamboat moves at the rate of ten miles every hour, her velocity is uniform; the revolution of the earth, from west to east, is a perpetual example of uniform motion. 2. Velocity is *accelerated*, when the rate of motion is constantly increased, and the moving body passes through unequal spaces in equal times. Thus, when a falling body moves sixteen feet during the first second, and forty-eight feet during the next second, its velocity is accelerated. A body falling from a height freely through the air, is the most perfect example of this kind of velocity. 3. *Retarded* velocity, is when the rate of motion of the body is constantly decreased, and it is made to move slower and slower. A ball thrown upwards into the air has its velocity constantly retarded by the attraction of gravitation, and, consequently, it moves slower every moment." 4. In cases of accelerated, and of retarded velocity, a distinction is observed between the *initial* and the *final* velocity of a body: the former is exhibited by the body when it commences its motion; the latter only after the lapse of a certain time: both are measured by the space which the body would have passed over, in one second, with the uniform initial or final velocity, as the case may be.

65. The following is a table of some of the principal velocities, expressed in English feet, taken from Peschel's Elements of Physics:—

MEAN VELOCITY OF

Rivers	3—4	feet in a second.
A very rapid stream, rarely .	13.3	„
Wind at a mean intensity . .	10.6	„
A storm	54	„
Very violent hurricane, not exceeding	128	„
Sound in an atmosphere at 32° F.	1089.4	„
At a mean temp. (60° F.) . .	1120	„
Atmospheric air rushing into a vacuum	1280	„
Bullet discharged from an air-gun, the air being condensed 100 times	697	„
Common musket ball . . .	1280	„
Rifle ball, at most . . .	1600	„
24lb. cannon ball, at most . .	2450	„
A point at the surface of the earth, under the equator . . .	1525.6	„
The earth's centre in her orbit round the sun. a mean . .	101061	„

or rather more than 19 English miles.

The steamboats on the Rhine, from Cologne to Düsseldorf, with the current	12.8—16 feet in a second. or 8.8—10.8 English miles per hour.
Average of 51 voyages during 4 years, ending June, 1834, by the admiralty steamers between Falmouth and Corfu . .	7¼ miles per hour
Average rate (according to Dr Renwick) of steamers between New York and Albany, exclusive of stoppages . . .	10½ ,,
Mail trains on Great Western Railway, including stoppages	25⅕ ,,
The fastest sailing vessel . . .	15 feet in a second.
The swiftest race-horse . . .	42—80 ,,

FORCE, OR MOMENTUM OF MOVING BODIES.

66. "The velocities of bodies are equal, when they pass over equal spaces in the same time; but the force with which bodies, moving at the same rate, overcome impediments, is in proportion to the quantity of matter they contain. This power, or force, is called the *momentum* of the moving body. Thus, if two bodies of the same weight move with the same velocity, their momenta will be equal. Two vessels, each of a hundred tons, sailing at the rate of six miles an hour, would overcome the same impediments, or be stopped by the same obstructions. Their momenta would therefore be the same.

67. "The force, or momentum of a moving body is in proportion to its quantity of matter, and its velocity. A large body moving slowly, may have less momentum than a small one moving rapidly. Thus, a bullet, shot out of a gun, moves with much greater force than a stone thrown by the hand. The momentum of a body is found by multiplying its quantity of matter by its velocity. Thus, if the velocity be two, and the weight 2, the momentum will be four. If the velocity be 6 and the weight of the body 4, the momentum will be 24." An iceberg moves slowly, but its momentum is prodigious, owing to its quantity of matter; a musket ball contains little matter, but its momentum is destructive, in consequence of its velocity. A body weighing only 3 pounds, and moving at a velocity of 300 feet in a second, will possess as much momentum as a body weighing 30 pounds, and moving at the rate of only 30 feet per second, for $300 \times 3 = 30 \times 30$.

68. *Action and Re-action.*—"If a moving body strike an

impediment, the force with which it strikes, and the resistance of the impediment, are equal. Thus, if a boy throw his ball against the side of the house, with the force of 3, the house resists it with an equal force, and the ball rebounds. If he throw it against a pane of glass with the same force, the glass having only the power of 2 to resist, the ball will go through the glass, still retaining one-third of its force. From observations made on the effects of bodies striking each other, it is found that *action and re-action are equal;* or, in other words, that force and resistance are equal. Thus, when a moving body strikes one that is at rest, the body at rest returns the blow with equal force. This is illustrated by the well known fact, that if two persons strike their heads together, one being in motion, and the other at rest, they are both equally hurt.

69. "The philosophy of action and re-action is finely illustrated by a number of ivory balls, suspended by threads, as in fig. 7, so as to touch each other. If the ball A be drawn from the perpendicular, and then let fall, so as to strike the one next to it, the motion of the falling ball will be communicated through the whole series, from one to the other. None of the balls, except F, will, however, appear to move. This will be understood, when we consider that the re-action of B is just equal to the action of A, and that each of the other balls, in like manner, acts and reacts on the other, until the motion of A arrives at F, which, having no impediment, or nothing to act upon, is itself put in motion. It is, therefore, reaction which causes all the balls except F to remain at rest.

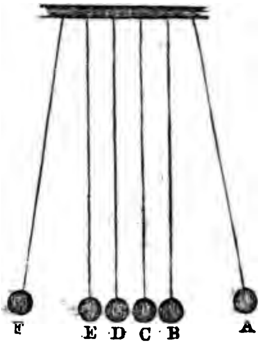


Fig. 7.

70. "It is by a modification of the same principle, that rockets are impelled through the air. The stream of expanded air, or the fire which is emitted from the lower end of the rocket, not only pushes against the rocket itself, but against the atmospheric air, which, re-acting against the air so expanded, sends the rocket along

71. "It was on account of not understanding the principles of action and re-action, that the man undertook to make a fair wind for his pleasure boat, to be used whenever he wished to sail. He fixed an immense bellows in the stern of his boat, not doubting but the wind from it would carry him along. But on making the experiment, he found that his boat went *backwards*, instead of forwards. The reason is plain. The re-action of the atmosphere on the stream of wind from the bellows, before it reached the sail, moved the boat in a contrary direction. Had the sails received the whole force of the wind from the bellows, the boat would not have moved at all, for then, action and re-action would have been exactly equal, and it would have been like a man's attempting to raise himself over a fence by the straps of his boots."

72. The law of action and re-action enables us to calculate the powers of animals and machines, as exerted for the purposes of locomotion, the momentum of the moving power being equal to the resistance of the body moved. It is usual, in such calculations, to express the amount of useful effect by stating the number of pounds which can be moved through the space of one foot or yard, in a second or minute of time. 1. The labour of a man, carrying the weight of 40lbs. through a space of $3\frac{1}{3}$ feet in a second, amounts to the exertion of a force of $3\frac{1}{3} \times 40 = 133\frac{1}{3}$ lbs., or the product of the weight multiplied by the velocity. 2. The power of an average horse, commonly termed *horse-power*, is equal to 33,000 lbs. raised one foot per minute, or 550 lbs. in a second. 3. When an engine, therefore, is said to be of one horse power, the expression means that the engine is capable of moving such a load through a space of one foot per minute; and, for every extra horse, an equal number of pounds is supposed to be added to the resistance of the engine. In one of Smeaton's engines, the power of which was estimated at 2268 pounds, the number of strokes per minute was ten, of six feet each; the power of the engine was, therefore, equal to the number of pounds multiplied by the number of strokes per minute, and by the number of feet in the stroke, or $2268 \times 10 \times 6 = 136,088$ lbs.; his engine was, consequently, of *four horse* power.

REFLECTED MOTION.

73. "It has been stated that all bodies when once set in motion, would continue to move straight forward, until some

impediment, acting in a contrary direction, should bring them to rest; continued motion without impediment being a consequence of the inertia of matter. Such bodies are supposed to be acted upon by a single force, and that in the direction of the line in which they move. Thus, a ball sent out of a gun, or struck by a bat, turns neither to the right nor left, but makes a curve towards the earth, in consequence of another force, which is the attraction of gravitation, and by which, together with the resistance of the atmosphere, it is finally brought to the ground.

74. "The kind of motion now to be considered is that which is produced when bodies are turned out of a straight line by some force, independent of gravity. A single force, or impulse, sends the body directly forward, but another force, not exactly coinciding with this, will give it a new direction, and bend it out of its former course. If, for instance, two moving bodies strike each other obliquely, they will both be thrown out of the line of their former direction. This is called *reflected* motion, because it observes the same laws as reflected light. The bounding of a ball; the skipping of a stone over the smooth surface of a pond; and the oblique direction of an apple, when it touches a limb in its fall, are examples of reflected motion.

75. "By experiments on this kind of motion, it is found that moving bodies observe certain laws, in respect to the direction they take in rebounding from any impediment they happen to strike. Thus, a ball, striking on the floor, or wall of a room, makes the same angle in leaving the point where it strikes, that it does in approaching it. 1. Suppose A, B, Fig. 8, to be a marble slab, or floor, and C to be an ivory ball, which has been thrown towards the

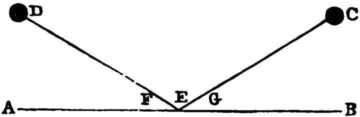


Fig. 8.

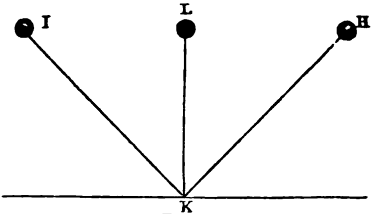


Fig. 9.

floor in the direction of the line C E; it will rebound in the direction of the line E, D, thus making the two angles F and G exactly equal. 2. If the ball approached the floor under a larger or smaller angle, its rebound would observe the same rule. Thus, if it fell in the line H K, Fig. 9, its rebound would be in the line K I, and if it was dropped perpendicularly from L to K, it would return in the same line to L. The angle which the ball makes with the perpendicular L K, in its approach to the floor, is called the *angle of incidence*, and that which it makes in departing from the floor in the same line, is called the *angle of reflection*, and these angles are always equal to each other."

COMPOUND MOTION.

76. *Simple* motion is that which results from the operation of a single force; but when two or more forces act in different directions on the same body, at the same time, the motion so produced is said to be *compound*. In every compound motion, the moving forces act in the same direction, or in diametrically opposite directions, or at some angle; in all these cases, the single force which represents the combined effects of all the forces, is called the *resultant*. In the first case, the resultant is the sum of all the forces, and their direction; and their direction is unchanged. In the second, the resultant is the difference of the forces, and the direction is that of the greater force; if the forces are equal, their effects are mutually neutralized, and no motion is produced. In the third case, the resultant is found by the laws of what is termed the *parallelogram of forces*, which will be readily understood by means of a diagram:—

77 "Suppose the ball A, Fig 10, to be moving with a certain velocity in the line B C, and suppose that at the instant when it came to the point A, it should be struck with an equal force in the direction of D E, as it cannot obey the direction of both these forces, it will take a course between them, and fly off in the direction of F. The reason of this is plain. The first force would carry the ball from B to C; the second would carry it from D to E, and these two forces being equal, gives it a direction just half way between the two, and therefore it is sent towards F. The line A F, is called the *diagonal of the square*, and results from the cross forces, B and D being equal to each other. If one of the moving forces is greater than the other, then the diagonal line

will be lengthened in the direction of the greater force, and instead of being the diagonal of a square, it will become the diagonal of a parallelogram, or oblong square.

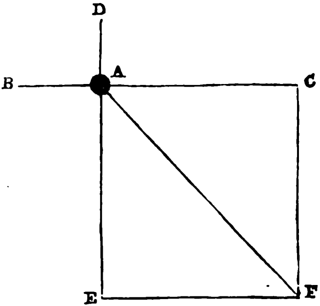


Fig. 10.

78. "Suppose the force in the direction of A B, should drive the ball with twice the velocity of the cross force C D, Fig 11, then the ball would go twice as far from the line C D, as from the line B A, and E F would be the diagonal of a parallelogram, whose length is double its breadth.

79. "Suppose a boat in crossing a river, is rowed forward at the rate of four miles an hour, and the current of the river is at the same rate, then the two cross forces will be equal, and the line of the boat will be the diagonal of a square, as in Fig 10. But if the current be four miles an hour, and the progress of the boat forward only two miles an hour, then the boat will go down stream twice as fast as she goes across the river, and her path will be the diagonal of a parallelogram, as Fig. 10, and therefore to make the boat pass directly across the stream, it must be rowed towards some point higher up the stream than the landing place; a fact well known to boatmen.

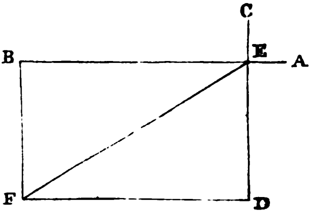


Fig. 11

CIRCULAR MOTION.

80. "*Circular motion* is the motion of a body in a ring, or circle, and is produced by the action of two forces. By one of these forces the moving body tends to fly off in a straight line, while, by the other, it is drawn towards the centre, and thus it is made to revolve, or move round in a circle. The

of the wheel. Thus, the centre of gravity in the wooden wheel, Fig. 14, would be at the axis on which it turns; but were the arm A, of iron, its centre of motion and of gravity would no longer be the same, but while the centre of motion remained as before, the centre of gravity would fall to the point A. Thus the centre of motion and of gravity, though often at the same point, are not always so.

85. "When the body is shaped irregularly, or there are two or more bodies connected, the centre of gravity is the point on which they will balance without falling. If the two balls A and B, Fig. 15, weigh each four pounds, the centre of gravity will be a point on the bar equally distant from each. But if one of the balls be heavier than the other, then the centre of gravity will, in proportion, approach the larger ball. Thus in Fig. 16, if C weighs two pounds, and D eight pounds, the centre of gravity will be four times the distance from C that it is from D.

Fig. 15.

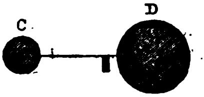


Fig. 16.

86. "In a body of equal thickness, as a board, or a slab of marble, but otherwise of an irregular shape, the centre of gravity may be found by suspending it, first from one point, and then from another, and marking by means of a plumb line the perpendicular ranges from the point of suspension. The centre of gravity will be the point where these two lines cross each other. Thus, if the irregular-shaped piece of board, Fig. 17, be suspended by making a hole through it at the point A, and at the same point suspending the plumb line C,

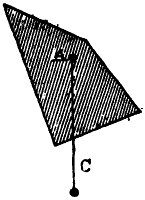


Fig. 17.

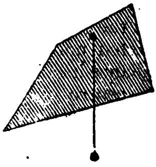


Fig. 18.

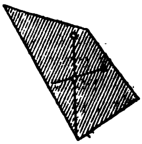


Fig. 19.

both board and line will hang in the position represented in the figure. Having marked this line across the board, let it be suspended again in the position of Fig. 18, and the perpendicular line again marked. The point where these lines cross each other, is the centre of gravity, as seen by Fig. 19.

87. "It is often of great consequence, in the concerns of life, that the subject of gravity should be well considered, since the strength of buildings, and of machinery, often depends chiefly on the gravitating point. Common experience teaches, that a tall object, with a narrow base, or foundation, is easily overturned; but common experience does not teach the reason, for it is only by understanding principles that practice improves experiment. An upright object will fall to the ground when it leans so much that a perpendicular line from its centre of gravity falls beyond its base. A tall chimney, therefore, with a narrow foundation, such as are commonly built at the present day, will fall with a very slight inclination. Now, in falling, the centre of gravity passes through the part of a circle, the centre of which is at the extremity of the base on which the body stands. This will be comprehended by Fig. 20. Suppose the figure to be a block of marble, which is to be turned over; by lifting at the corner A, the corner B would be the centre of its motion, or the point on which it would turn. The centre of gravity, C, would therefore describe the part of a circle, of which the corner, B, is the centre. It will be obvious, after a little consideration, that the greatest difficulty we should find in turning over a square block of marble, would be, in first raising up the centre of gravity, for the resistance will constantly become less, in proportion as the point approaches a perpendicular line over the corner B, which, having passed, it will fall by its own gravity.

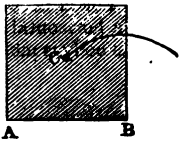


Fig. 20.

88. "The difficulty of turning over a body of a particular form, will be more strikingly illustrated by the figure of a triangle, or low pyramid. In Fig. 21, the centre of gravity is so low, and the base so broad, that in turning it over, a great proportion of its whole weight must be raised. Hence we see the firmness of the pyramid in theory,

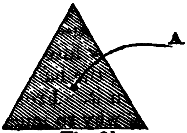


Fig. 21

and experience proves its truth; for buildings are found to withstand the effects of time, and the commotions of earthquakes, in proportion as they approach this figure. The most ancient monuments of the art of building, now standing, the pyramids of Egypt, are of this form.

89. "When a ball is rolled on a horizontal plane, the centre of gravity is not raised, but moves in a straight line parallel to the surface of the plane on which it rolls, and is consequently always directly over its centre of motion. 1. Suppose, Fig. 22, A is the plane on which the ball moves, B the line on which the centre of gravity moves, and C a plumb line, showing that the centre of gravity must always be exactly over the centre of motion, when the ball moves on a horizontal plane; then we shall see the reason why a ball moving on such a plane, will rest with equal firmness in any position, and why so little force is required to set it in motion. For in no other figure does the centre of gravity describe a horizontal line over that of motion, in whatever direction the body is moved. 2. If the plane is inclined downwards, the ball is instantly thrown into motion, because the centre of gravity then falls forward of that of motion, or the point on which the ball rests. This is explained by Fig. 23, where A is the point on which the ball rests, or the centre of motion, C the perpendicular line from the centre of gravity as shown by the plumb weight C. If the plane is inclined upward, force is required to move the ball in that direction, because the centre of gravity then falls behind that of motion, and therefore the centre of gravity has to be constantly lifted. This is also shown by Fig. 23, only considering the ball to be moving up the inclined plane, instead of down it. From these principles, it will be readily understood, why so much force is required to roll a heavy body, as a hogshead of sugar, for instance, up an inclined plane. The

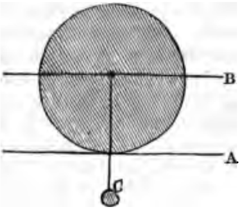


Fig. 22.

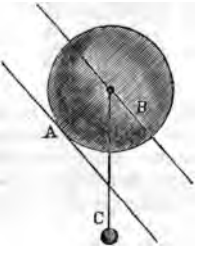


Fig. 23.

centre of gravity falling behind that of motion, the weight is constantly acting against the force employed to raise the body.

90. "From what has been stated, it will be understood, that the danger that a body will fall, is in proportion to the narrowness of its base, compared with the height of the centre of gravity above the base. Thus a tall body, shaped like Fig. 24, will fall, if it lean but very slightly, for the centre of gravity being far above the base, at A, is brought over the centre of motion, B, with little inclination, as shewn by the plumb line. Whereas a body shaped like Fig. 25, will not fall, until it leans much more, as again shewn by the direction of the plumb line. We may learn from these comparisons, that it is more dangerous to ride in a high carriage than in a low one, in proportion to the elevation of the vehicle, and the nearness of the wheels to each other, or in proportion to the narrowness of the base, and the height of the centre of gravity. A load of hay upsets where the road raises one wheel but little higher than the other, because it is high, and broader on the top than the distance of the wheels from each other; while a load of stone is very rarely turned over, because the centre of gravity is near the earth, and its weight between the wheels, instead of being far above them.

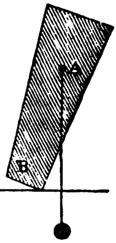


Fig. 24.

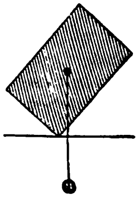


Fig. 25.

91. "In man, the centre of gravity is between the hips, and hence, were his feet tied together, and his arms tied to his sides, a very slight inclination of his body would carry the perpendicular of his centre of gravity beyond the base, and he would fall. But when his limbs are free to move, he widens his base, and changes the centre of gravity at pleasure, by throwing out his arms, as circumstances require. 1. When a man runs, he inclines forward, so that the centre of gravity may hang before his base, and in this position, he is obliged to keep his feet constantly advancing, otherwise he would fall forward. 2. A man standing on one foot, cannot throw his body forward without at the same time throwing his other foot backward, in order to keep his centre of gra-

vity within the base. 3. A man, therefore, standing with his heels against a perpendicular wall, cannot stoop forward without falling, because the wall prevents his throwing any part of his body backward. A person, little versed in such things, agreed to pay a certain sum of money for an opportunity of possessing himself of double the sum, by taking it from the floor with his heels against the wall. The man, of course, lost his money, for in such a posture, he could hardly reach lower than his own knee. 4. The base, on which a man is supported, in walking or standing, is his feet, and the space between them. By turning the toes out, this base is made broader, without taking much from its length, and hence persons who turn their toes outward, not only walk more firmly, but more gracefully, than those who turn them inward. 5. In consequence of the upright position of man, he is constantly obliged to employ some exertion to keep his balance. This seems to be the reason why children learn to walk with so much difficulty, for after they have strength to stand, it requires considerable experience, so to balance the body as to set one foot before the other without falling. 6. By experience in the art of balancing, or of keeping the centre of gravity in a line over the base, men sometimes perform exploits, which, at first sight, appear altogether beyond human power, such as dining with the table and chair standing on a single rope, dancing on a wire, &c.

92. "No form under which matter exists, escapes the general law of gravity, and hence vegetables, as well as animals, are formed with reference to the position of this centre, in respect to the base. It is interesting, in reference to this circumstance, to observe how exactly the tall trees of the forest conform to this law. The pine, which grows a hundred feet high, shoots up with as much exactness, with respect to keeping its centre of gravity within the base, as though it had been directed by the plumb line of a master builder. Its limbs towards the top are sent off in conformity to the same law; each one growing in respect to the other, so as to preserve a due balance between the whole. It may be observed, also, that where many trees grow near each other, as in thick forests, and consequently where the wind can have but little effect on each, that they always grow taller than when standing alone on the plain. The roots of such trees are also smaller, and do not strike so deep as those of trees standing alone. A tall pine, in the midst of

the forest, would be thrown to the ground by the first blast of wind, were all those around it cut away. Thus, the trees of the forest not only grow so as to preserve their centres of gravity, but actually conform, in a certain sense, to their situation.

CENTRE OF INERTIA.

93. "Inertia, like gravity, resides equally in every particle of matter, has like it also a centre in each particular body, and this centre is the same with that of gravity. 1. In a bar of iron, six feet long, and two inches square, the centre of gravity is just three feet from each end, or exactly in the middle. If, therefore, the bar is supported at this point, it will balance equally, and because there are equal weights on both ends, it will not fall. This, therefore, is the centre of gravity. 2. Now, suppose the bar should be raised by raising up the centre of gravity, then the inertia of all its parts would be overcome equally with that of the middle. The centre of gravity is, therefore, the centre of inertia. 3. The centre of inertia being that point which being lifted, the whole body is raised, is not, therefore, always at the centre of the body. Thus, suppose the same bar of iron, whose inertia was overcome by raising the centre, to have balls of different weights attached to its ends, then the centre of inertia would no longer remain in the middle of the bar, but would be changed to the point A, Fig. 26, so that to lift the whole, this point must be raised instead of the middle, as before.

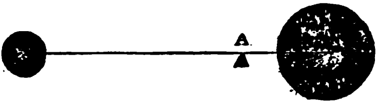


Fig. 26.

EQUILIBRIUM.

94. "When two forces counteract, or balance each other, they are said to be in *equilibrium*. It is not necessary for this purpose that the weights opposed to each other should be equally heavy, for we have just seen that a small weight placed at a distance from the centre of inertia, will balance a large one placed near it. To produce equilibrium, it is only necessary that the weights on each side of the support should

mutually counteract each other, or if set in motion that their momenta should be equal. A pair of scales are in equilibrium when the beam is in a horizontal position. To produce equilibrium in solid bodies, therefore, it is only necessary to support the centre of inertia or gravity. If a body, or several bodies connected, be suspended by a string, as in Fig. 27, the point of support is always in a perpendicular line above the centre of inertia. The plumb line, D, cuts the bar connecting the two balls at this point. Were the two weights in this figure equal, it is evident that the hook, or point of support, must be in the middle of the string, to preserve the horizontal position. When a man stands on his right foot, he keeps himself in equilibrium by leaning to the right, so as to bring his centre of gravity in a perpendicular line over the foot on which he stands.

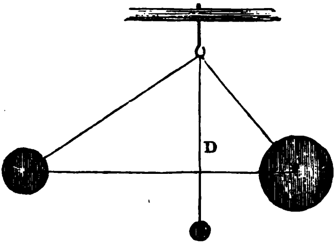


Fig. 27.

CURVILINEAR OR BENT MOTION.

95. "We have seen that a single force acting on a body drives it straight forward (§ 73.) and that two forces acting crosswise, drive it midway between the two, or give it a diagonal direction. (§ 77.) *Curvilinear motion* differs from both these, the direction of the body being neither straight forward nor diagonal, but through a line which is curved. This kind of motion may be in any direction; but when it is produced in part by gravity, its direction is always towards the earth. A stream of water from an aperture in the side of a vessel, as it falls towards the ground, is an example of a curved line; and a body passing through such a line, is said to have *curvilinear* motion. Any body projected forward, as a cannon ball or rocket, falls to the earth in a curved line. It is the action of gravity across the course of the stream, or the path of the ball, that bends it downwards, and makes it form a curve. This motion is therefore the result of two forces, that of projection and that of gravity. The shape of the curve will depend on the velocity of the stream or ball.

When the pressure of the water is great, the stream near the vessel is nearly horizontal, because its velocity is in proportion to the pressure. When a ball first leaves the cannon, it describes but a slight curve, because its projectile velocity is then greatest.

96. "The curves described by jets of water, under different degrees of pressure, are readily illustrated by tapping a tall vessel in several places, one above another. Suppose

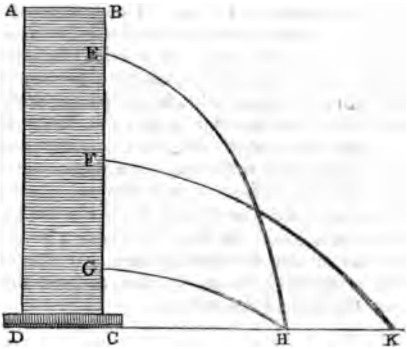


Fig. 28.

Fig. 28 to be such a vessel filled with water, and pierced as represented; the streams will form curves, differing from each other, as seen in the figure. The action of gravity being always the same, the shape of the curve described, as just stated, must depend on the velocity of the moving body; but whether the projectile force be great or small, the moving body, if thrown horizontally, will reach the ground from the same height in the same time. This, at first thought, would seem improbable, for, without consideration, most persons would assert, very positively, that if two cannons were fired from the same spot, at the same instant, and in the same direction, one of the balls falling half a mile, and the other a mile distant, the ball which went to the greater distance would take the longer time in performing its journey. But it must be remembered' that the projectile force does not in the least interfere with the force of gravity. A ball flying horizontally at the rate of a thousand feet per second, is attracted downwards with precisely the same force as one flying only a hundred feet per second, and must therefore descend the same distance in the same time.

97. "The distance to which a ball will go, depends on the force of impulse given it the first instant, and consequently on its projectile velocity. If it move slowly, the distance will be short; if more rapidly, the space passed over will be greater. It makes no difference, then, in respect to the descent of the ball, whether its projectile motion be fast or slow, or whether it move forward at all. This is demonstrated by experiment. Suppose a cannon to be loaded with a ball, and placed on the top of a tower at such a height from the ground that it would take just three seconds for a cannon ball to descend from it to the ground if let fall perpendicularly. Now, suppose the cannon to be fired in an exact horizontal direction, and at the same instant the ball to be dropped towards the ground. They will both reach the ground at the same instant, provided its surface be a horizontal plane from the foot of the tower to the place where the projected ball strikes. This will be made plain by Fig. 29, where A D is the perpendicular line of the descending ball, A G the curvilinear path of that projected from the cannon, and D G the horizontal line from the foot of the tower.

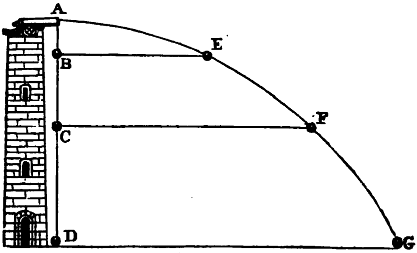


Fig. 29.

The reason why the two balls will reach the ground at the same time is easily comprehended. During the first second, suppose that the ball which is dropped reaches B; during the next second it falls to C, and at the end of the third second it strikes the ground. Meantime, the ball shot from the cannon is projected forward with such velocity, as to reach E in the same time that the other is falling to B.

But the projected ball falls downwards exactly as fast as the other, for it meets the line B E, which is parallel to the horizon, at the same instant. During the next second, the projected ball reaches F, while the other arrives at C; and here again they have both descended through the same downward space, as is seen by the line C F, which is parallel with the other. During the third second the ball from the cannon will have nearly spent its projectile force, and therefore, its motion downward will be greater, while its motion forward will be less than before. The reason of this will be obvious, when it is considered, that in respect to gravity, both balls follow exactly the same law, and fall through equal spaces in equal times. Therefore, as the falling ball descends through the greatest space during the last second, so that from the cannon having now a less projectile motion, its downward motion is more direct, and, like all falling bodies, its velocity is increased as it approaches the earth.

98. "From these principles it may be inferred that the horizontal motion of a body through the air, does not in the least interfere with its gravitating motion towards the earth, and therefore that a rifle ball, or any other body projected forward horizontally, will reach the ground in exactly the same period of time, as one that is let fall perpendicularly from the same height. The two forces acting on bodies which fall through curved lines, are the same as the centrifugal and centripetal forces, already explained; the centrifugal, in the case of the ball, being caused by the powder; the centripetal, being the action of gravity.

99. "Now, it is obvious that the space through which a cannon ball, or any other body, can be thrown, depends on the velocity with which it is projected, for the attraction of gravitation and the resistance of the air acting perpetually, the *time* which a projectile can be kept in motion, through the air, is only a few moments. If, however, the projectile be thrown from an elevated situation, it is plain that it would strike at a greater distance than if thrown on a level, because it would remain longer in the air. Every one knows that he can throw a stone to a greater distance, when standing on a steep hill, than when standing on the plain below.

100. "Bonaparte, it is said, by elevating the range of his shot, bombarded Cadiz from the distance of five miles. Perhaps, then, from a high mountain, a cannon ball might be thrown to the distance of six or seven miles. 1. Suppose the

circle, Fig. 30, to be the earth, and A a high mountain on its surface. Suppose that this mountain reaches above the atmosphere, or is fifty miles high, then a cannon ball might perhaps reach from A to B, a distance of eighty or a hundred miles, because the resistance of the atmosphere being out of the calculation, it would have nothing to contend with, except the attraction of gravitation. If, then, one degree of force or velocity, would send it to B, another would send it to C; and if the force was increased three times, it would fall at D, and if four times, it would pass to E. If now we suppose the force to be about ten times greater than that with which a cannon ball is projected, it would not fall to the earth at any of these points, but would continue its motion, until it again came to the point A, the place from which it was first projected. It would now be in equilibrium, the centrifugal force being just equal to that of gravity, and therefore it would perform another, and another revolution, and so continue to revolve around the earth perpetually. 2. The reason why the force of gravity will not ultimately bring it to the earth, is, that during the first revolution, the effect of this force is just equal to that exerted in any other revolution, but neither more nor less; and therefore, if the centrifugal force was sufficient to overcome this attraction during one revolution, it would also overcome it during the next. It is supposed, also, that nothing tends to affect the projectile force except that of gravity, and the force of this attraction would be no greater during any other revolution than during the first. 3. In other words, the centrifugal and centripetal forces are supposed to be exactly equal, and to mutually balance each other; in which case, the ball would be, as it were, suspended between them. As long, therefore, as these two forces con-

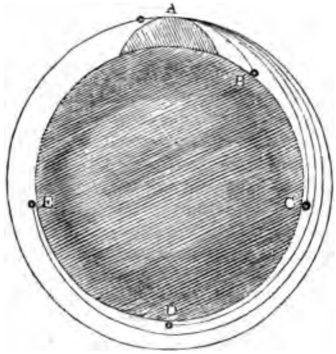


Fig. 30.

tinued to act with the same power, the ball would no more deviate from its path, than a pair of scales would lose their balance without more weight on one side than on the other. 4. It is these two forces which retain the heavenly bodies in their orbits, and in the case we have supposed, our cannon ball would become a little satellite, moving perpetually round the earth.

RESULTANT MOTION.

101. "Suppose two men to be sailing in two boats, each at the rate of four miles an hour, at a short distance opposite to each other, and suppose, as they are sailing along in this manner, one of the men throws the other an apple. In respect to the boats, the apple would pass directly across, from one to the other, that is, its line of direction would be perpendicular to the sides of the boats. But its actual line through the air would be oblique, or diagonal, in respect to the sides of the boats, because in passing from boat to boat, it is impelled by two forces, viz. the force of the motion of the boat forward, and the force by which it is thrown by the hand across this motion.

102. "This diagonal motion of the apple is called the *resultant*, or the resulting motion, because it is the effect or result of the two motions resolved into one. Perhaps this will be more clear by Fig. 31, where A B and C D are supposed to be the sides of the two boats, and the line E F that of the apple. Now, the apple, when thrown, has a motion with the boat at the rate of four miles an hour from C towards D, and this motion is supposed to continue just as though it had remained in the boat. Had it remained in the boat during the time it was passing from E to F, it would have passed from E to H. But we suppose it to have been thrown at the rate of eight miles an hour in the direction towards G, and if the boats are moving south, and the apple thrown towards the east, it would pass, in the same time, twice as far towards the east as it did towards the south. Therefore, in respect to the boats, the apple would pass in a perpendicular line from the side of one to that of the other, because they are both in motion; but in respect to

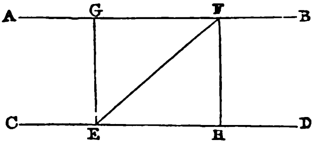


Fig. 31.

one perpendicular line drawn from the point where the apple was thrown, and a parallel line with this drawn from the point where it strikes the other boat, the line of the apple would be oblique. This will be clear, when we consider that when the apple is thrown, the boats are at the points E and G, and that when it strikes, they are at H and F, these two points being opposite to each other. The line E F, through which the apple is thrown, is called the *diagonal of a parallelogram*, as already explained under compound motion.

103. "On the above principle, if two ships, during a battle, are sailing before the wind at equal rates, the aim of the gunners will be exactly the same as though they stood still; whereas, if the gunner fires from a ship standing still, at another under sail, he takes his aim forward of the mark he intends to hit, because the ship would pass a little forward while the ball is going to her. And so, on the contrary, if a ship in motion fires at another standing still, the aim must be behind the mark, because, as the motion of the ball partakes of that of the ship, it will strike forward of the point aimed at.

104. "For the same reason, if a ball be dropped from the topmast of a ship under sail, it partakes of the motion of the ship forward, and will fall in a line with the mast, and strike the same point on the deck, as though the ship stood still. If a man upon the full run drops a bullet before him from the height of his head, he cannot run so fast as to overtake it before it reaches the ground. It is on this principle, that if a cannon ball be shot up vertically from the earth, it will fall back to the same point; for although the earth moves forward while the ball is in the air, yet, as it carries this motion with it, so the ball moves forward also in an equal degree, and therefore comes down at the same place. Ignorance of these laws induced the story-making sailor to tell his comrades, that he once sailed in a ship which went so fast, that when a man fell from the mast-head, the ship sailed away, and left the poor fellow to strike into the water behind her.

PENDULUM.

105. "A *pendulum* is a heavy body, as a piece of brass, or lead, suspended by a wire or cord, so as to swing backwards and forwards. When a pendulum swings, it is said to *vibrate*, and that part of a circle through which it vibrates is called

its *arc*. The times of the vibration of a pendulum are very nearly equal, whether it pass through a greater or less part of its arc. Suppose A and B Fig. 32, to be two pendulums of equal length, and suppose the weights of each are carried, the one to C, and the other to D, and both let fall at the same instant; their vibrations would be equal in respect to time, the one passing through its arc from C to E and so back again in the same time that the other passes from D to F, and back again. The reason of this appears to be, that when the pendulum is raised high, the action of gravity draws it more directly downwards, and it therefore acquires, in falling, a greater comparative velocity than is proportioned to the trifling difference of height." From the facts above stated, the following *law* may be deduced:—Pendulums of equal length vibrate, or oscillate, at the same place in equal times, and are said to be *isochronous*. The heights to which such pendulums are elevated, must not differ considerably, nor must they be raised more than 10° beyond the perpendicular.

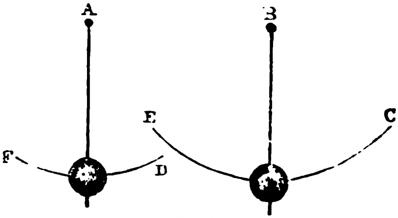


Fig. 32.

106. "In the common clock, the pendulum is connected with wheel work, to regulate the motions of the hands, and with weights, by which the whole is moved. The vibrations of the pendulum are numbered by a wheel having sixty teeth, which revolves once in a minute. Each tooth, therefore, answers to one swing of the pendulum, and the wheel moves forward one tooth in a second. Thus the second hand revolves once in every sixty beats of the pendulum, and as these beats are seconds, it goes round once in a minute. By the pendulum, the whole machine is regulated, for the clock goes faster or slower according to its number of vibrations in a given time. The number of vibrations which a pendulum makes in a given time depends upon its length, because a long pendulum does not perform its journey to and from the corresponding points of its arc so soon as a short one. As the motion of the clock is regulated entirely by

the pendulum, and as the number of vibrations are as its length, the least variation in this respect will alter its rate of going. To beat seconds, its length must be about 39 inches. In the common clock, the length is regulated by a screw, which raises or lowers the weight. But as the rod to which the weight is attached is subject to variations of length in consequence of the change of the seasons, being contracted by cold, and lengthened by heat, the common clock goes faster in winter than in summer.

107. "Various means have been contrived to counteract the effects of these changes, so that the pendulums may continue of the same length during the whole year. Among inventions for this purpose, the *gridiron* pendulum is considered the best; and it is so called because it consists of several rods of metal connected together at each end. The principle on which this pendulum is constructed is derived from the fact that some metals dilate more by the same degrees of heat than others. Thus brass will dilate twice as much by heat, and consequently contract twice as much by cold, as steel. If, then, these differences could be made to counteract each other mutually, given points at each end of a system of such rods would remain stationary the year round, and thus the clock would go at the same rate in all climates, and during all seasons. This important object is accomplished by the following means:—

108. "Suppose the middle rod, Fig. 33, to be made of brass, and the two outside ones of steel, all of the same length. Let the brass rod be firmly fixed to the cross pieces at each end. Let the steel rod A be fixed to the lower cross piece, and B to the upper cross piece. The rod A at its upper end passes through the cross piece, and, in like manner, B passes through the lower one. This is done to prevent these small rods from playing backwards and forwards as the pendulum swings. Now, as the middle rod is lengthened by the heat twice as much as the outside ones, and the outside rods together are twice as long as the middle one, the actual length of the pendulum can neither be increased nor diminished by the variations of temperature.

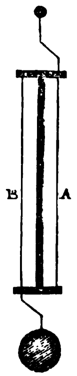


Fig. 33.

109. "To make this still plainer, suppose the lower cross piece, Fig. 34, to be standing on a table, so that it could not

be lengthened downwards; and suppose, by the heat of summer, the middle rod of brass should increase one inch in length. This would elevate the upper cross piece an inch, but at the same time, the steel rod A swells half an inch, and the steel rod B half an inch, therefore the two points, C and D, would remain exactly at the same distance from each other.

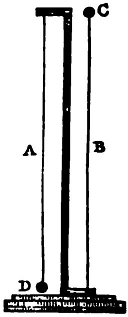


Fig. 34.

110. "As it is the force of gravity which draws the weight of the pendulum from the highest point of its arc downwards, and as this force increases or diminishes as bodies approach towards the centre of the earth, or recede from it, so the pendulum will vibrate faster or slower in proportion as this attraction is stronger or weaker. Now, it is found that the earth at the equator rises higher from its centre than it does at the poles, for towards the poles it is flattened. The pendulum, therefore, being more strongly attracted at the poles than at the equator, vibrates faster. For this reason, a clock which would keep exact time at the equator, would gain time at the poles, for the rate at which a clock goes depends on the number of vibrations its pendulum makes. Therefore pendulums, in order to beat seconds, must be shorter at the equator, and longer at the poles. For the same reason, a clock which keeps exact time at the foot of a high mountain, would move slower at its top." Under the equator, the length of a pendulum beating seconds is 439.2066 Paris lines; and under the poles 441.5928 Paris lines; the entire difference between these two extremes being only 2.3862 Paris lines, or little more than ⅕th of an English inch; in the latitude of London, the length of such a pendulum is 39⅛, or, more accurately, 39.13929 inches, at the temperature of 62° Fahr.—*Peschel.*

111. "*Metronome.*—There is a short pendulum used by musicians for marking time, which may be made to vibrate fast or slow as occasion requires. This little instrument is called a *metronome*, and, besides the pendulum, consists of several wheels and a spiral spring, by which the whole is moved. This pendulum is only ten or twelve inches long, and instead of being suspended at the end like other pendulums, the rod is prolonged above the point of suspension,

and there is a ball placed near the upper, as well as at the lower extremity. This arrangement will be understood by Fig. 35, where A is the axis of suspension, B the upper ball, and C the lower one. Now, when this pendulum vibrates from the point A, the upper ball constantly retards the motion of the lower one, by in part counterbalancing its weight, and thus preventing its full velocity downwards.

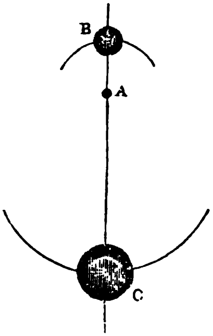


Fig. 35.

112. "Perhaps this will be more apparent by placing the pendulum, Fig. 36, for a moment on its side, and across a bar, at the point of suspension. In this position, it will be seen that the little ball would prevent the large one from falling with its full weight, since, were it moved to a certain distance from the point of suspension, it would balance the large one, so that it would not descend at all. It is plain, therefore, that the comparative velocity of the large ball will be in proportion, as the small one is moved to a greater or less distance from the point of suspension. The metronome is so constructed, the little ball being made to move up and down on the rod at pleasure, and thus its vibrations are made to beat the time of a quick or a slow tune, as occasion requires. By this arrangement, the instrument is made to vibrate every two seconds, or every half, or quarter, of a second, at pleasure."

Fig. 36.

QUESTIONS ON CHAP. I.

1. What is the subject of Natural Philosophy? What is meant by matter? What is an atom or molecule? How is a body constituted? Enumerate the physical properties of matter.—2. What is extension, and to what qualities of matter does it relate? Show that it has no relation to size or shape. What is the common designation of this property?—3. What connexion exists between extension and figure? What kind of bodies exhibit regularity of figure? Show that the volume of a body has no necessary relation to its figure.—4. What is meant by impenetrability? What effect is really produced, on driving a nail into a piece of wood? State some other cases in proof of the impenetrability of matter. How is this property turned to account in the use of the diving-bell?—5. What is divisibility? Illustrate this property by examples taken from unorganized, and from organized matter.—6. What is meant by inertia? Why will a ball roll further on ice than on the ground? Why, with the same force of projection, will the ball move further in air than on ice? What would result from projecting the ball into free space? What are the causes which resist the perpetual motion of bodies? Why will a top spin, or a pendulum swing, longer in an exhausted vessel than in air? Give an example of continued motion, without the existence of air and friction. Why is a passenger standing in a carriage thrown backward, when the carriage is suddenly put in motion? Why is he thrown forward, when the carriage is suddenly stopped?—7. What is meant by indestructibility? How may a liquid, which has been reduced to vapour, be restored to its former condition? When animal or vegetable bodies undergo decay, what becomes of their constituent particles? Is there any ground for believing that matter is, under any circumstances, annihilated? Describe the process of what is called destructive distillation, and show that nothing is thereby destroyed.—8. What is meant by attraction?—9. How does the attraction of cohesion operate? By what principle in nature is its operation counteracted? Under how many forms is matter exhibited, and by what operations are these forms sustained? Mention a particular body, which is capable of assuming each of these forms.—10. Give instances of cohesive attraction in solid bodies. In which of the solid bodies does this property most strongly exist? Why are the particles of fluid bodies more easily separated than those of solids? —11. What forms do fluids take when their particles are left to

their own arrangement? Give examples of this law.—12. How is the globular form which liquids assume accounted for? If the particles of a body are free to move, and are equally attracted towards the centre, what must be its figure?—13. What is meant by attraction of gravitation? Can one body attract another without being itself attracted? How is it proved that bodies attract each other?—14. By what law, or rule, does the force of attraction increase? By what rule does it decrease?—15. Do bodies attract in proportion to bulk, or quantity of matter? What would be the difference of attraction between a cubic inch of lead, and a cubic inch of cork? Why would there be so much difference?—16. What is meant by capillary attraction? How is this kind of attraction illustrated with a glass tube? Why does the water rise higher in the tube, than it does on the outside?—17. Give some common illustrations of this principle. —18. Explain generally, the difference between a mechanical mixture and a chemical compound.—19. What is meant by chemical attraction? By what other name is this kind of attraction known? Give some instances of chemical affinity, as exhibited between different bodies.—20. How may oil and water be made to unite? What is the composition thus formed called? How does an acid destroy this compound? What is the reason that hard water will not wash?—21. Give some instances of change of properties, as induced by chemical action?—22. What is a natural magnet? What is meant by magnetic attraction? What is an artificial magnet? What is a magnetic needle? What is its use?—23. What is meant by electrical attraction? What is electrical repulsion?

24. Enumerate the peculiar qualities of bodies.—25. What is density? What bodies are most dense? Show that density is not an essential quality of metals. How may this quality be increased in metals?—26. What is rarity? To what class of bodies is the term generally applied? How is rarefaction of the atmosphere produced? What is the relation between rarefaction of the atmosphere and elevation from the surface of the earth?—27. Is the quality of hardness proportional to the density of a body? Why will glass scratch gold or platinum? Which are the hardest metals? What metal can be made hard or soft at pleasure?—28. What is meant by elasticity? How is it known that bodies possess this property? Mention several elastic solids. Give examples of inelastic solids. Do liquids possess this property? What are the most elastic of all substances?—29. Show how the sonorous quality of metals is allied to their hardness and elasticity.—30. What is brittleness? Give

an instance in which the qualities of brittleness and elasticity are united. How may iron, steel, and brass be rendered brittle?—31. What is meant by malleability? Upon what other qualities does this quality depend? Which are the malleable metals? Illustrate the malleability of gold. How may metals which have become brittle, be rendered malleable? What is meant by welding?—32. What is meant by ductility? To what extent has the ductility of gold been carried? Are the most malleable metals also the most ductile? Give an instance in proof of the contrary.—33. What is tenacity? From what does this quality arise? What elementary vegetable tissue is highly tenacious, and to what purpose is it consequently applied? How is the tenacity of metals ascertained? How is the tenacity of metals impaired?—34. What is a crystal? State some examples of crystallization.—35. What are the common crystalline forms of the metals? How may the facility of procuring metallic crystals be tested?—36. What is meant by a dimorphous body? Illustrate this phenomenon in the case of sulphur.

38. What is meant by terrestrial gravitation? What is meant by the weight of a body? What is the tendency of all falling bodies, with respect to terrestrial gravitation? In what direction will two falling bodies from opposite parts of the earth tend, in respect to each other? In what direction will one from half way between them meet their line? How is this shown by the figure? Are the terms *up* and *down* relative or positive, in their meaning? What is understood by *down* in any part of the earth? Suppose a ball be let fall at twelve and then at six o'clock, in what direction would the lines of their descent meet each other? Suppose two balls to descend from opposite sides of the earth, what would be their direction in respect to each other?—39. What is said concerning the motions of falling bodies? How is this increased velocity illustrated? Why is there any more danger in jumping from the house-top than from a chair?—40. What number of feet does a falling body pass through during the first second? How far does it fall during the next second? How far during the third, the fourth, the fifth second?—41. State the law of gravitation. What relation exists between the mass and the gravity of a body? What is the relation between the distance from which a body falls, and the force of gravity with which it falls? Explain the *rule*, with reference to the table. Suppose the accelerating force should cease at the beginning of the third second, how far would it fall during that second? Why does it fall more than this during that second? How many times 16 feet does a body move in

the fourth second?—42. How may the height of a precipice, or the depth of a well, be estimated, with reference to the foregoing principles? What are the fundamental elements by which the velocity of a falling body may be computed?—43. Is the velocity of a falling body calculated from actual measurement, or by a machine? Describe the operation of Mr Atwood's machine for estimating the velocities of falling bodies. After the small weight is taken off by the ring, why does the large weight continue to descend?—44. Does this machine show the actual velocity of a falling body, or only its increase?—45. How does Mr Atwood's machine show how much the celerity of a body depends upon gravity, and how much on acquired velocity?—46. Suppose the times of a falling body are as the numbers 1, 2, 3, 4, what will be the numbers representing the spaces through which it falls? Suppose a body falls 16 feet the first second, how far will it fall the third second?—47. Would it be possible for a rifle ball to acquire a greater force by falling, than if shot from a rifle? How long would it take the moon to come to the earth according to the law of increased velocity? How long would it take the earth to fall to the sun?—48. What familiar illustrations are given of the force acquired by the velocity of falling bodies?—49. Will a small and a large body fall through the same space in the same time? On what parts of a mass of matter does the force of gravity act?—50. Is the effect of gravity in proportion to bulk, or quantity of matter? Were the mass of the earth doubled, how much more should we weigh than we do now? Suppose one body moving towards another, three times as large, by the force of gravity, what would be their proportional velocities? How is this illustrated?—51. Does a large body attract a small one with any more force than it is attracted? Suppose a body weighing 200 pounds to be placed at a distance from the earth, with how much force does the earth attract the body? With what force does the body attract the earth? Suppose a man in one boat, pulls with a force of 100 pounds at a rope fastened to another boat, what would be the force on each boat? How is this illustrated?—52. Suppose the body falls towards the earth, is the earth set in motion by its attraction? Why is not the earth's motion towards it perceptible?—53. What distance would a body, the tenth part of a mile in diameter, placed at the distance of a tenth part of a mile, attract the earth towards it?

54. What effect has the force of gravity on bodies moving upward?—55. Are upward and downward motion governed by the same laws?—56. What is the difference between the up-

ward and returning velocity of the same body?—57. Why will not a sack of feathers and a stone of the same size fall through the air in the same time?—58. Does this affect the truth of the general law, that the weights of bodies are as their quantities of matter?—59. What would be the effect on the fall of light and heavy bodies, were the atmosphere removed? —60. How is it proved that a feather and a guinea will fall through equal spaces in the same time, where there is no resistance?—61. How will you define motion? State the three laws of motion. What is that power called, which puts a body in motion? What would be the consequence were all motion to cease?—62. How is motion divided? What is absolute motion? What is relative motion? What is the earth's relative velocity in respect to Mars?—63. In what respect is a man in a steamboat at rest, and in what respect does he move?—64. What is velocity? When is velocity uniform? When is velocity accelerated? Give illustrations of these two kinds of velocity. What is meant by retarded velocity? Give an example of retarded velocity. What is the distinction between initial and final velocity? How are they both measured?—65. What is the mean velocity of rivers, of wind, of atmospheric air rushing into a vacuum, of a rifle ball, and of the earth's centre in her orbit round the sun?—66. What is meant by the momentum of a body? When will the momenta of two bodies be equal? Give an example.—67. When has a small body more momentum than a large one? By what rule is the momentum of a body found? —68. When a moving body strikes an impediment, which receives the greater shock? What is the law of action and re-action? How is this illustrated?—69. When one of the ivory balls strikes the other, why does the most distant one only move? —70. On what principle are rockets impelled through the air? —71. In the experiment with the boat and bellows, why did the boat move backwards? Why would it not have moved at all, had the sail received all the wind from the bellows?—72. How does the law of action and re-action enable us to calculate the powers of animals and machines, in effecting locomotion? How is the amount of useful effect calculated? How is the labour of a man, carrying a certain weight through a certain space, in a certain time, estimated? What is the power of an average horse? How is the power of an engine to be ascertained?—73. Suppose a body is acted on, and set in motion by a single force, in what direction will it move?—74. What is the motion called, when a body is turned out of a straight line by another force? What illustrations can you give of reflected motion?—

75. What laws are observed in reflected motion? Suppose a ball to be thrown on the floor in a certain direction, what rule will it observe in rebounding? What is the angle called, which the ball makes in approaching the floor? What is the angle called, which it makes in leaving the floor? What is the difference between these angles?—76. What is compound motion? In what three directions may the moving forces act, in compound motion?—77. Suppose a ball, moving with a certain force, to be struck crosswise with the same force, in what direction will it move? Suppose it to be struck with half its former force, in what direction will it move? What is the line A F, Fig. 10, called?—78. What is the line E F, Fig. 11, called?—79. How are these figures illustrated?—80. What is circular motion? How is this motion produced? What is the centrifugal force? What is the centripetal force? Suppose the centrifugal force should cease, in what direction would the body move? Suppose the centripetal force should cease, where would the body go?—81. Explain Fig. 12. What constitutes the centrifugal force of a body moving round in a circle? How is this illustrated?—82. What is the axis of motion? What is the centre of motion? Give illustrations?—83. What part of a revolving wheel has the greatest centrifugal force? Why? Why must large wheels, turning with great velocity, be strongly made? What would be the consequence, were the velocity of the earth 17 times greater than it is?

84. Where is the centre of gravity in a body? Where is the centre of gravity in a wheel, made of wood? If one side is made of wood, and the other of iron, where is the centre of gravity? Are the centres of motion and of gravity always the same?—85. When two bodies are connected, as by a bar between them, where is the centre of gravity?—86. In a board of irregular shape, by what method is the centre of gravity found?—87. In what direction must the centre of gravity be from the outside of the base, before the object will fall? In falling, the centre of gravity passes through part of a circle; where is the centre of this circle? In turning over a body, why does the force required constantly become less and less?—88. Why is there less force required to overturn a cube, or square, than a pyramid of the same weight?—89. When a ball is rolled on a horizontal plane, in what direction does the centre of gravity move? Explain Fig. 23. Why does a ball on a horizontal plane rest equally well in all positions? Why does it move with little force? If the plane is inclined downwards, why does the ball roll in that direction? Why is force required to move a ball up an inclined

plane?—90. What is the danger that a body will fall proportioned to? Why is a body shaped like Fig. 24, more easily thrown down, than one shaped like Fig. 25? Hence, in riding in a carriage, how is the danger of upsetting proportioned?—91. Where is the centre of gravity in man? Why will a man fall with a slight inclination, when his feet and arms are tied? Why cannot one who stands with his heels against a wall stoop forward? Why does a person walk most firmly, who turns his toes outward? Why does not a child walk as soon as he can stand? In what does the art of balancing, or walking on a rope, consist?—92. What is observed in the growth of the trees of the forest, in respect to the laws of gravity?—93. Are the centres of inertia and of gravity the same? Where is the centre of inertia in a body, or a system of bodies? Why is the point of inertia changed, by fixing different weights to the ends of the iron bar?—94. What is meant by equilibrium? To produce equilibrium, must the weights be equal? When is a pair of scales in equilibrium? When a body is suspended by a string, where must the support be with respect to the point of inertia?—95. What is meant by curvilinear motion? What are examples of this kind of motion? What two forces produce this motion?—96. On what does the shape of the curve depend? How are the curves described by jets of water illustrated? What difference is there in respect to the time taken by a body to reach the ground, whether the curve be great or small? Why do bodies forming different curves from the same height, reach the ground at the same time? Suppose two balls, one flying at the rate of a thousand, and the other at the rate of a hundred feet per second, which would descend most during the second?—97. Does it make any difference in respect to the descent of the ball, whether it has a projectile motion or not? Suppose then, one ball be fired from a cannon, and another let fall from the same height at the same instant, would they both reach the ground at the same time? Explain Fig. 32, showing the reason why the two balls will reach the ground at the same time. Why does the ball approach the earth more rapidly in the last part of the curve, than in the first part?—98. What is the force called which throws a ball forward? What is that called, which brings it to the ground? On what does the distance to which a projected body may be thrown depend?—99. Why does the distance depend on the velocity?——100. Explain Fig. 30. Suppose the velocity of a cannon ball shot from a mountain fifty miles high, to be ten times its usual rate, where would it stop? When would this ball be in equilibrium? Why would not the force of gravity ultimately bring the ball to the earth? After the first revolution, if the two forces continued the same, would not the motion of the ball be perpetual?—101. Suppose two boats sailing at the same rate, and in the same direction, if an apple be tossed from one to the other, what will be its direction in respect to the boats? What would be its line through the air, in respect to the boats?—102. What is this kind of motion called? Why is it called resultant motion? Explain Fig. 31. Why would the line of the apple be actually perpendicular in respect to the boats, but oblique in respect to parallel lines drawn from where it was thrown and where it struck?—103. How is this further illustrated? When the ships are in equal motion, where does the gunner take his aim? Why does he aim forward of the mark, when the other ship is in motion? If a ship in motion fires at one standing still, where must be the aim? Why, in this case, must the aim be behind the mark?—104. What other illustrations are given of resultant motion?

105. What is a pendulum? What is meant by the vibration of a pendulum? What is that part of a circle called, through which it swings? Why does a pendulum vibrate in equal time, whether it goes through a small or large part of its arc? State the *law* of the vibration of pendulums.—106. Describe the common clock. How many vibrations has the pendulum in a minute? On what depends the number of vibrations which a pendulum makes in a given time? What is the medium length of a pendulum beating seconds? Why does a common clock go faster in winter than in summer?—107. What is necessary in respect to the pendulum, to make the clock go true the year round? What is the principle on which the gridiron pendulum is constructed? What are the metals of which this instrument is made?—108. Explain Fig. 33, and give the reason why the length of the pendulum will not change by the variations of temperature.—109. Explain Fig. 34.—110. What is the downward force which makes the pendulum vibrate? Explain the reason why the same clock would go faster at the poles and slower at the equator. How can a clock which goes true at the equator be made to go true at the poles? Will a clock keep equal time at the foot, and on the top of a high mountain? Why will it not?—111. What is the metronome? How does this pendulum differ from common pendulums? How does the upper ball retard the motion of the lower one?—112. How is the metronome made to go faster or slower at pleasure?

CHAP. II.

OF HEAT—THE REPULSIVE QUALITY IN MATTER.

113. *General Remarks.*—It has been already observed (§ 9.) that, while the attraction of cohesion tends to unite the particles of matter, its operation is powerfully counteracted by an antagonist principle, universally diffused through nature. This is the repulsive quality in matter, commonly termed Heat, and its general tendency is to cause expansion, by separation of the particles of bodies among themselves. The term Heat denotes, generally, the *sensation* experienced on touching a body of a higher temperature than that of the hand. But Heat appears to be in a constant state of motion and of interchange between different bodies, passing from those which are warmer to those which are colder, until it finally settles into a state of *equilibrium.* If accumulated in any body, this accumulation cannot be preserved; the excess will pass away into other bodies. If, for instance, a number of substances of different temperatures be introduced into an apartment, where there is no actual source of heat, they will soon acquire the same temperature. Hence it has been supposed that Heat is a material substance of a very subtile kind, existing in a greater or less degree in all bodies; when thus understood, it is termed *Caloric*, and is considered to be the *cause* of the sensation of heat. If the essential cause of heat be still involved in mystery, many of its properties and effects have been ascertained, and skilfully applied to the cultivation of science and the uses of life. Heat is one of the principal agents in chemistry, producing very remarkable changes in all material objects: the conversion of ice into water, of water into steam, are familiar illustrations of its influence. Heat is imponderable: bodies undergo no appreciable change in weight by the addition or subtraction of heat. The phenomena of Heat may be arranged and studied in the following order:—

SOURCES OF HEAT.

114. Heat exists in all bodies in different degrees, not only in those which to our sensation are cold, but even in those of the lowest temperatures. The principal *sources of heat* are the sun, electricity, chemical action, and mechanical action.

Each of these may be illustrated by the following examples:—1. By collecting and concentrating the rays of the *sun* in burning-glasses, considerable effects may be produced at great distances: with 40 of these, a board of beech wood, covered with tar, was set on fire by Buffon, almost instantaneously, at the distance of 66 feet; with 128 mirrors, a board of pine wood, likewise covered with tar, was set on fire at a distance of 150 feet; and with 117 mirrors, small pieces of money were melted.—2. By means of *Electricity* metals may be ignited, fused, and in some cases, if required, volatilized; gases may be united, which resist every other means employed to effect their union; most combustible bodies may be inflamed, as alcohol, phosphorus, gunpowder—and this indifferently, whether the electric sparks be procured from ice, or from red-hot iron. By the galvanic action, which is a form of electricity, the most intense degree of heat hitherto known has been procured.—3. Heat is produced by *Chemical Action.* A familiar instance occurs in the slaking of lime; if water be poured upon a piece of well-burnt lime, it is absorbed, and the lime appears for a short time as dry as before; but in a few minutes the lime swells, bursts into pieces, and becomes hotter than boiling water, while clouds of hot steam issue from it. *Combustion* is an illustration of chemical action, and is attended by heat, the degree of which varies with the nature of the burning body. The *Organic Action* of air-breathing animals affords another illustration of chemical action. Animal heat appears to result from a sort of slow combustion, by which the carbon, or inflammable principle of the blood, combines with the oxygen of the air in the act of respiration.—4. Heat is also a result of *Mechanical Action*, as of percussion, friction, and condensation. A piece of cold iron may be so dexterously struck by a hammer on an anvil, as to become hot, even red hot. The evolution of heat, attendant on percussion, appears to depend on the diminution of bulk in the body struck: on submitting a piece of copper to the strokes of the coining-press, Berthollet found that with the first stroke, 17.3°, Fahr. of heat were evolved; with the second, 7.5°; and with the third, only 1.9°. The effect of friction in producing heat is perceived by rubbing of the hands for the purpose of warming them; and the practice of greasing the axles of carriage-wheels is to prevent their setting fire to the wood by friction. Savage tribes are said to procure fire by rubbing pieces of dry wood together. Count

Rumford ascertained that, in the process of boring a brass cannon, 7½ inches in diameter, the borer performing thirty-two revolutions in a minute, with a pressure of 10,000 pounds, a sufficient amount of heat was evolved to boil eighteen pounds of water, in which it was immersed, in 2½ hours. Two pieces of ice, rubbed together, gradually melt, owing to the evolution of heat from them. It has been found by experiment that a body never ceases to give out heat by friction, however long the process is continued. Lastly, it is possible to ignite tinder, by rapidly condensing a portion of air by means of a piston.

COMMUNICATION OF HEAT.

115. Heat is communicated between bodies in contact with each other, or between the contiguous parts of the same body, by *Conduction;* and between bodies at a distance from each other, by *Radiation.*

116. *Conduction of Heat.*—If one extremity of a metallic body, as a rod of iron, be placed in a fire, the heat is gradually communicated, or *conducted*, to the other extremity.

117. The conduction of heat is chiefly confined to *solid bodies;* and as solids vary considerably in their consistency, their conducting powers vary proportionably. The gradual conduction of heat through a body may be familiarly illustrated by fixing pieces of cork with wax to a brass rod, at different distances, and applying heat to one end of the rod: the pieces of cork will fall off in succession. Dense and compact bodies are generally good conductors, while those which are light and porous conduct heat imperfectly. Instances of this difference are of daily occurrence: metallic instruments which are required to be held in the hand, when hot, are furnished with wooden handles, metals being good conductors, and wood an imperfect one. A needle, held with one extremity in the flame of a candle, becomes almost immediately so much heated as to burn the fingers; but one end of a glass rod of equal length may be held in the flame until it melts, the other end being little affected. If a piece of writing paper be rolled round a smooth brass bar, and placed over a gas burner, the heat is conducted away so rapidly by the metal, that the paper is not even discoloured; if the paper be rolled round a cylinder of wood, and similarly exposed to heat, it becomes discoloured, owing to the feebler conducting power of the wood; but, if

the paper be rolled round a piece of charcoal, and exposed to the same heat, it immediately ignites. In particular cases, however, there is no relation between the density of bodies and their conducting power: platinum, for instance, is the most dense of the metals, and yet it is one of the worst conductors among them; and glass is a worse conductor than many substances of less than half its density. Of the metals, silver is stated by Ingenhousz to be the best conductor; then copper, gold, tin, iron, and lastly lead. Stones, glass, and minerals, come next in conducting power. Bricks are very imperfect conductors, and, owing to their consequent detention of heat, they are employed, when heated and wrapped in cloth, for keeping the feet warm in cold weather. Still lower in conducting power are ranged light and porous bodies, as hair, fur, wool, &c.; charcoal is one of the worst conductors. In proportion as the particles of bodies are separated from each other, their conducting power diminishes: thus, the filings of the metals have very inferior conducting powers to those of the metals themselves. Sawdust conducts heat more feebly than wood. *Snow* is an imperfect conductor of heat, and is therefore of great use in protecting vegetation from frosts and severe cold; if snow falls early in the season, and remains late, a good crop of grain may be expected; in the absence of snow, the crop is often said to be "winter-killed." So great is the protecting power of snow, that in Siberia, where the air is 70 degrees below the freezing point, the temperature of the earth is stated to be seldom colder than that of the freezing point itself. *Sand* is a very imperfect conductor: the red-hot balls, employed by the garrison at Gibraltar to destroy the Spanish floating batteries, were carried from the furnaces to the bastions in *wooden* barrows, with only a layer of sand interposed; and this was found sufficient to prevent the balls, though in a high state of incandescence, from setting fire to the wood. The following table presents the different conducting powers of several solids:—

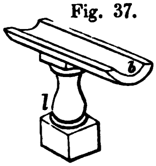
	Conducting power.		Conducting power.
Gold	1000	Tin	304
Silver	973	Lead	179.6
Copper	898	Marble	23.6
Platinum	381	Porcelain	12.2
Iron	374.3	Clay	11.4
Zinc	363		

118. It is upon the principle of imperfect conduction that certain substances are selected as articles of *Clothing*. The object of clothing is, in cold weather, to prevent the escape, or conduction, of heat *from* the body; and, in warm weather, to prevent the too rapid communication, or conduction, of heat *to* the body. Hence, animals are clothed in fur, wool, down, and feathers; and man in great measure borrows his clothing from them. It has been observed that the finer the texture of woollen cloth is, the more imperfectly does it conduct heat; and that the animals of cold climates are furnished with finer and softer wool and fur than those of warmer countries. The comparative conducting powers of various articles of clothing are exhibited in the following table by Count Rumford. A thermometer in the open air occupied 576 seconds in cooling down 135°; but when surrounded by the following substances, it occupied the periods of time annexed to each, the worst conductor being that in which it occupied the longest time in cooling:—

	No. of seconds.		No. of seconds.
Spun silk . .	917	Raw silk . .	1284
Fine lint . .	1032	Beaver's fur .	1296
Cotton wool .	1046	Eider down .	1305
Sheep's wool .	1118	Hare's fur . .	1315

119. A very interesting phenomenon connected with the communication of heat between metals, was discovered by Mr. Trevelyan. In many cases in which metals at different temperatures are brought into contact, particularly when a heated curved bar of brass *b*, is made to rest upon a cold cylinder of lead *l*, the hot metal is thrown into a state of vibration, accompanied by the production of a musical tone. This effect appears to depend upon a repulsive power existing between the heated surfaces, which is increased in this case by the low conducting power of the lead, the surface of which admits of being strongly heated by the brass. Professor Forbes observes that the most powerful vibrations are produced between the best conductors and the worst conductors of heat, the latter being the cold bodies.

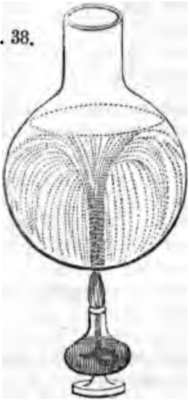
Fig. 37.



120. *Liquid bodies* are very imperfect conductors of heat. If heat be applied to the surface of a liquid in a vessel, as

when ether is poured on the surface of water and inflamed, the heat passes downwards so slowly, as to have caused a doubt whether it is conducted at all by the liquid, and not rather by the sides of the vessel. Dr. Murray, however, contrived to make a vessel of ice, and filled it with oil at the temperature of 32°; a thermometer was fixed some way beneath the surface of the liquid. On applying heat to the surface, the thermometer rose 5½° in 7 minutes, viz. to 37½°; this small amount of heat must have passed through the oil, for the walls of the vessel would have been melted by it. In most liquids, however, the power of conducting heat is so feeble, that a portion of liquid may be boiled off from the surface in a long tube, while the temperature at a little distance beneath the surface is scarcely affected.—But if heat be applied to the lower part of a vessel containing water, the whole mass soon becomes hot, and we might hence be led to conclude that the liquid is a good conductor of heat. The explanation of the fact is this:—The heat being applied to the liquid, the heated portions expand, become lighter, and ascend rapidly through the liquid; these portions are replaced by others, which are successively heated, and pass upwards; thus, ascending and descending currents are established, as shown in Fig. 38, until the whole mass is heated. The diffusion of the heat depends, therefore, upon the motion produced among the several parts of the liquid. It is an act of *Conveyance*, and not of conduction from particle to particle. The motions produced by heat in the above experiment may be clearly shown by placing some coloured and insoluble powder in the flask of water: the coloured matter will continue to ascend and descend, until it becomes entirely diffused throughout the liquid. Similar effects are produced on applying cold to the surface of a liquid: the cooled portions become heavier, descend, and force up the warmer and lighter portions, until an equilibrium of temperature is established.—Liquids, like

Fig. 38.



solids, appear to conduct, or *convey*, better in proportion as they are more dense. Thus, spirit of wine, a very light liquid, is a bad conveyer; oil is heavier, and conveys better; proof spirit is still heavier, and conveys proportionably better; water is heavier than any of the preceding liquids, and exceeds them all in its conveying power; and mercury, the heaviest of all liquids, is comparatively a good conveyer of heat.

121. *Aeriform bodies*, as gases and vapours, are also very imperfect conductors of heat. The usual mode of diffusion of heat among aeriform bodies appears to be, as in liquids, by an act of *conveyance;* the heated portions ascend, carrying the heat with them; hence, in heating apartments by hot air, the flues are placed in the floors or lowest part. Metals are painful to the touch, when heated to 120°; water is capable of scalding at 150°; but the human body may be exposed to air at a temperature of nearly 300°, without having its heat increased beyond two or three degrees. Workmen are in the habit of entering ovens, in manufactories of moulds of plaster of Paris, in which the thermometer is almost 100° above the temperature of boiling water, and of remaining in them for several minutes at a time. In such an atmosphere the contact of a good conductor would cause pain, as was experienced by a gentleman who entered the oven with his silver mounted spectacles on; his nose was burned. Sir Joseph Banks and Sir Charles Blagden were able to endure the heat of a room at the temperature of 264°, or 52° above that of boiling water; but they found that their hands could not endure the heat of their watch-chains or metallic buttons. The effect of heated air upon the animal frame is, however, much more intense when the air is in motion than when it is at rest, owing to the continued application of fresh portions to the surface: a temperature which in the one case would produce no uneasiness, would in the other be intolerable. Similar results are experienced in the application of excessively cold air to the surface of the human body: in the northern regions, a temperature below that of freezing mercury can be supported without injury provided the weather be calm, but, when applied in the form of a current of wind, its effects are so severe as to freeze the extremities.

122. Upon the principle of the diffusion of heat among

aeriform bodies by *conveyance*, may be explained the phenomena of *Winds*, which are currents of air. The mean temperature of the atmosphere near the equator, and at the level of the sea, is upwards of 80°, while in the polar regions it is constantly below 32°. Hence, a given bulk of air at the level of the sea is much lighter at the equator than an equal bulk at the same level at the poles. The air at the equator, therefore, ascends, and its place is occupied by the colder and heavier air from the poles; the displaced air flows over, as it were, and forms an upper current in the direction of the poles; it is cooled in its course, and drawn down to supply the deficiency in the extra-tropical regions; and thus a continual circulation is kept up. These opposite motions are represented in the subjoined figure. Let A B C denote a portion of the earth's surface, A being in the direction of the north pole, C in that of the south pole, B representing the equator. The currents of the air pass in the direction of the arrows. The wind, therefore, from A to B would blow, on the surface of the earth, from north to south, while from E to A the upper current would pass from south to north, until it reached A, when it would change its direction, and turn towards the south. The currents in the southern hemisphere, being regulated by similar laws, would assume similar directions.

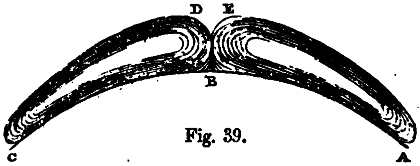
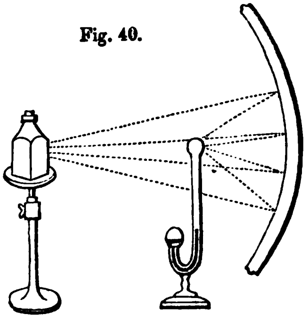


Fig. 39.

123. *Radiation of Heat.*—If a body, as a piece of iron, be heated, and allowed to cool in the open air, the heat gradually passes off from its surface on all sides, in right lines, in the form of *radii*, or rays, in the same manner as light proceeds from a candle or the sun. Radiant heat is supposed to move with the same velocity as light; viz. at the rate of 192,000 miles per second. The effect of radiant heat diminishes as the square of the distance; thus, if its effect at the distance of one foot be reckoned as 1, at two feet it

will be as 1-4th, at three feet as 1-9th, at four feet as 1-16th, and so on.—Different bodies vary in their power of radiation, and therefore do not cool, after having been heated, with equal rapidity. Leslie found that the rapidity with which bodies cool, depends more upon the condition of their *surface*, than upon the nature of their *substance;* and that rough and porous bodies radiate very powerfully, while polished metallic surfaces radiate very feebly. He filled a bright tin vessel with hot water, and having placed a thermometer in it, found that the temperature of the water fell half way to that of the apartment in 156 minutes; but, on covering the vessel with a thin coating of lamp-black, the temperature fell to an equal extent in 81 minutes, or about half the time it required with the bright surface. If the vessel be wrapped in linen, or coated with white or black paint, the cooling is similarly accelerated. A simple experiment may be performed with merely two thermometers, the one having its bulb coated with lamp-black, the other being clean; on raising them both to the same temperature by exposure to a fire, and allowing them to cool, the mercury in the blackened one falls much more rapidly than that in the other. In determining the radiating power of different surfaces, Leslie used square tin canisters, the surfaces of which were coated with different substances, and which were filled with hot water. The surfaces were presented, successively, to a metallic mirror, having the bulb of a differential thermometer placed in its focus, as shown in the annexed figure. In these experiments, a surface covered with lamp-black caused a rise of temperature equal to 100; a papered surface, 98; a glass surface, 90; and a metallic surface only 12. In heating apartments by steam or hot water, the surfaces of the tubes are blackened, in order that the heat may be diffused more

Fig. 40.



rapidly. The following table exhibits the different radiating powers of various substances—

	Radiating Power.		Radiating power.
Lamp-black	100	Tarnished lead	45
Writing paper	98	Clean lead	19
Sealing wax	95	Polished iron	15
Crown glass	90	Tin plate, gold, silver, copper	12
Plumbago	75		

124. The *Deposition of Dew* has been shown by Dr. Wells to depend upon the cold produced by the radiation of heat from the surface of the earth. When the direct influence of the sun is withdrawn, the surface of the earth radiates a portion of its heat into the surrounding space; and thus the air immediately in contact with it becomes cooled, and the watery vapour, which is always present in it, is condensed and deposited in the form of dew. The difference between the radiating powers of different surfaces produces corresponding effects on the deposition of dew: one portion of the earth's surface, or one portion of herbage, may be covered with dew, while another portion in the immediate neighbourhood is perfectly dry. That the deposition of dew depends on the radiation of heat is shown by the following circumstances. 1. Dew is always most abundant during calm and cloudless nights, and in situations freely exposed to the atmosphere. Whatever interferes with the process of radiation, has a decided effect on the deposition of dew. Hence, the slightest covering or shelter, as that of thin matting, or even muslin, is sufficient to protect the objects beneath it from the cold, the effect of radiation, and consequently, to prevent the formation of dew,—a fact well known to gardeners, of which they avail themselves in protecting tender plants from frost. Similar effects are produced by matters interposed at a great distance from the earth's surface: clouds effectually prevent the radiation of heat from the earth's surface, so that cloudy nights are always warmer than those which are clear, and there is, consequently, on such nights, little or no deposition of dew. 2. Dr Wells has shown that the quantity of dew which is deposited on different substances, under similar circumstances, is proportional to the radiating power of their surfaces. On exposing a plate of metal and a quantity of wool together, a large quantity of dew is con-

densed on the wool, while scarcely a trace of dew is found on the metal; wool, being the better radiator, falls to a lower temperature than the metal.—From dew there is an insensible transition to *Hoar Frost*, which is in fact only frozen dew, and indicative of greater cold. It is found, therefore, that frosty nights, like simply dewy nights, are calm and clear. On a calm night, the temperature of a grass plot is frequently 10° or 15° lower than that of the air at a few feet above it. Hence, in our climate, vegetables are liable to be exposed at night during ten months of the year to a freezing temperature; and even in July and August to a temperature only 2° or 3° warmer. And hence it is that trees of lofty growth frequently escape being injured by frost, while plants nearer the ground are quite destroyed.

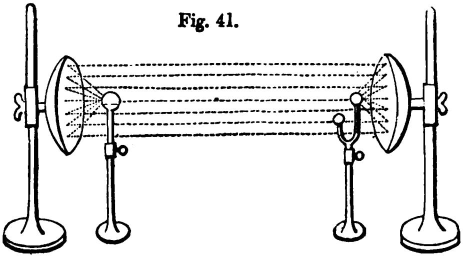
DISTRIBUTION OF HEAT.

125. There are three ways by which the rays of heat, as they fall upon the surface of a solid or liquid body, may be disposed of:—1, they may be *reflected*, or rebound from the surface;—2, they may be *absorbed*, or received into the substance of the body;—or, 3, they may be *transmitted*, or pass directly through its substance. In the first and third cases, the temperature of the body, on which the rays fall, is entirely unaffected; in the second, it is increased.

126. *Reflexion of Heat.*—Radiant Heat is capable of being *reflected* like light, and indeed obeys somewhat similar laws. Those surfaces, however, which reflect light most perfectly, are not equally adapted to the reflexion of heat. Polished metals are the best reflectors of heat; while glass, which reflects light most perfectly, reflects comparatively little heat; thus, tin-plate reflects about eight times as much heat as a glass mirror. Surfaces which *radiate* heat freely, *reflect* but little of the heat radiated upon them, while those which radiate feebly, reflect much; hence, radiation and reflexion are in inverse proportion. Metals, when polished, are the best reflectors, and the worst radiators, of heat; it is owing to their feeble radiating power that bright metallic covers are employed at table, and that metallic tea-pots are preferred to those made of porcelain and stoneware; and it is owing to their ready reflecting power, and their consequent dismissal of heat, that metallic reflectors remain cold, although they collect much heat in their foci. Glass, on the contrary, is a powerful radiator, and a feeble reflector, of

heat.—Very instructive experiments may be performed by means of a pair of concave metallic mirrors. These should be placed exactly opposite each other, with their principal axes in the same line, as represented in the above figure. In the focus of one mirror is placed a red-hot ball of iron; in the focus of the other, a differential thermometer. The dotted lines represent the rays of heat, as they pass from the hot body to the nearest mirror, are reflected from that to the opposite one, and from this again to the thermometer. The thermometer indicates the quantity of heat which has thus been once radiated, and twice reflected. By this means gunpowder may be ignited. If a canister containing hot water, or a lighted taper, be substituted for the ball of iron, the heat radiated from these bodies and reflected from the mirrors will sensibly affect the thermometer. If a cold body be substituted for the hot one, the thermometer indicates a lower temperature. This apparent radiation of cold is usually ascribed to the thermometer being, in this instance, the radiating body, giving off its heat to the colder body. The true explanation of the phenomenon is this:—When the thermometer is in the focus of one mirror, and no body in the focus of the other, all the rays of heat from the surrounding bodies which pass through this second focus, are reflected upon the thermometer; whereas, when a body of ice is placed in this focus, these rays are intercepted by it, and the thermometer falls for want of them.

Fig. 41.



127. *Absorption of Heat.*—Radiant heat is *absorbed* with different facilities by different surfaces. Those surfaces which *radiate* heat most readily, *absorb* heat also with readiness,

whereas those which radiate feebly, do not readily absorb heat. Lamp-black, which is the best radiator, is also the best absorber, of heat; polished metals, on the other hand, which radiate very imperfectly, are found to absorb also imperfectly; their absorbing, like their radiating power, is improved when their surface is roughened or tarnished. Again, those surfaces which *reflect* little, are found to *absorb* freely, and *vice versâ*. These opposite effects may be readily perceived on holding a glass mirror, and a metallic mirror, before the fire; the former absorbs, the latter reflects, the heat. Hence it may be stated, that the absorbing power of surfaces is directly as their radiating power, and inversely as their reflecting power. The power of absorption of the sun's rays depends much upon the *colour* of the absorbing body. Dr Franklin placed pieces of differently coloured cloths upon snow, and found that the snow melted more rapidly under black than under red cloth—more rapidly under red than under white cloth.

128. *Transmission of Heat.*—Radiant heat has the power of being *transmitted* through transparent bodies. The rays of the sun pass through glass, without warming it; and, generally speaking, heat of great intensity obeys laws somewhat analogous to those of light under similar circumstances. But heat of low intensity, radiating from terrestrial bodies, is partly intercepted as it passes through transparent objects; the higher the temperature of the radiant body, the greater is the number of rays transmitted. Thus, it was observed by Delaroche that, from a body heated to 182°, only 1-40th of all the heat given off was transmitted through a glass screen; from a body at 960°, as much as 1-4th appeared to pass through the screen. Melloni found that heat, after being transmitted through one plate of glass, becomes less subject to absorption in passing through a second: thus, of 1000 rays of heat emitted from an oil flame, 451 were intercepted in passing through four plates of glass of equal thickness, in the following order:—381 rays were intercepted by the first plate, 43 by the second, 18 by the third, and 9 by the fourth. A considerable number of rays are *absorbed* on entering the first layers of a transparent body, but the rays which pass through these layers may penetrate to a considerable depth. The transmission of heat through bodies does not depend on their transparency: a piece of smoky, brown rock-crystal, which was fifty-eight times thicker than a

transparent plate of alum, transmitted 19 rays, while the alum transmitted only 6. Bodies which transmit heat are termed by Melloni *diathermanous*, as bodies which transmit light are termed *diaphanous*, or transparent. Of all diaphanous bodies, water is the least diathermanous. The proportion of heat from different sources, which passes through a plate of glass, 1-50th of an inch in thickness, was found by Melloni to be as follows:—

	Rays transmitted.	Rays absorbed.
Of 100 rays from the flame of an oil lamp	54	46
——————red-hot platinum	37	63
——————blackened copper, heated to 732° F.	12	88
——————heated to 212° F.	0	100

Of all diathermanous bodies, rock-salt alone transmits the same quantity of heat, from whatever source derived,—viz. 92 per cent.

EFFECTS OF HEAT.

129. *Effects of Heat upon the Senses.*—The different conducting powers of heat, already described, lead to certain deceptive effects, when estimated with reference to our *senses*. 1. The air of a temperate apartment *feels* warm to a person previously exposed to cold, and cold to a person who has been exposed to heat.—2. If one hand be placed upon a hot body, the other upon a cold body, and then both hands upon a body of intermediate temperature, the *sensation* of heat is perceived by the cold hand, and that of cold by the warm one; so that, with reference to the senses, the same body will *feel* at the same time both warm and cold.—3. If a piece of metal, and a piece of cork, both at the ordinary temperature of the air, be applied to the skin, the metal *feels* cold, the cork warm. If these two substances be immersed for a long time in boiling water, then withdrawn and rapidly dried, the metal *feels* exceedingly hot, the cork scarcely more than warm. In both cases, the temperature of the two bodies is actually the same; the difference of sensation, in the former case, is owing to the metal withdrawing the heat *from* the hand more rapidly than the cork; in the latter case, it is owing to the metal communicating its heat *to* the hand more rapidly than the cork. In other words, the difference of

sensation is owing to the difference of temperature existing between the substance and the hand which touches it, and to the metal being a good conductor, and the cork a bad one. A thermometer applied to each, would indicate the same temperature. The most perfect conductors produce the strongest *sensations*, when they are warmer or colder than the hand which touches them; if warmer, they communicate heat rapidly; if colder, they abstract it rapidly. *Heat* and *cold* are, therefore, so far as our *sensations* are concerned, merely relative terms. A body is cold when its temperature is lower than our own, and when it has the power of conducting heat rapidly; on the other hand, it is warm, when its temperature is higher than our own, and when it has also the power of conducting heat rapidly.

130. *Expansion and Contraction.*—All bodies, when heated, *expand*, or increase in bulk; and, on cooling, they *contract*, or return to their original dimensions.

131. *Solid bodies* expand much less than those which are liquid or aëriform. A bar of iron *a*, made to fit easily in a gauge *b*, when cold, will, when heated to redness, be found to have increased both in length and thickness, so as no longer to fit the gauge. On cooling, the bar will again fill the same spaces as before. No two solid bodies expand equally by the same addition of heat. Of solids, metals expand the most; and there appears in most cases to be a relation between the expansibility and the fusibility of metals. Thus, lead, tin, and zinc, are more readily fused than copper, silver, and iron; the former metals are also more expansible than the latter, by the same addition of heat. A rod of lead, of 351 inches in length, expands one inch in length, on being heated from the freezing to the boiling point of water; gold expands one inch in 682, and flint-glass one inch in 1248. The relative degrees of expansion which different bodies undergo at low temperatures are ascertained by means of an instrument called a *pyrometer*. A rod of metal, *a*, is laid upon the rests; with one extremity it touches an immoveable screw *b*, with the other it touches a moveable index *c*, which traverses a

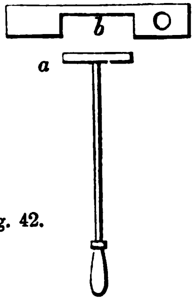
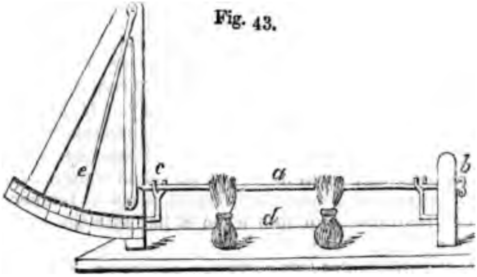


Fig. 42.

scale with a multiplied motion. The rod is heated by spirit lamps, and the degree of its expansion is indicated on the scale *e*. The increase in general bulk is about three times greater than that in length. Thus, glass, which increases in length one part in 1248, increases in general bulk three parts in 1248, or one part in 416. In some crystals, expansion does not take place uniformly in all directions; rhomboidal calcareous spar, for instance, increases in length, on being heated, and *contracts* in another direction; an angle of this substance, on being heated from the freezing to the boiling point of water, alters 8½ minutes of a degree. In order to observe this effect, it is necessary to select crystals which have their sides and angles unequal.

Fig. 43.



132. *Liquid bodies* expand much more than solids. The expansion of a liquid may be seen on applying the finger to the bulb of a common thermometer: the liquid increases in bulk by the warmth, and rises in the tube. Liquids expand in different degrees, those being the most expansible which require the least heat to make them boil. Thus, water expands more than mercury, spirits of wine more than water, ether more than spirits of wine. On being heated from the freezing to the boiling point of water, alcohol expands 1-9th of its volume, oil of turpentine 1-14th, water 1-22d, and mercury 1-55th. The different expansive powers of two liquids may be readily seen on immersing two glass bulbs with tubes attached to them, the one containing water, the other alcohol, in equal quantities, into a vessel of hot water: the alcohol will be found to rise in the tube about twice as high as the water.—Water, at a certain range of temperatures, exhibits a remarkable *exception* to the law of expan-

sion by heat and contraction by cold. The freezing point of water being 32°, it would be expected that water, on cooling, would continue to contract at every degree till it fell to this temperature. But the fact is otherwise. When the temperature has fallen to 40°, or perhaps 39½, the water not only ceases to contract, but actually begins to *expand*, and continues to expand with every additional degree of reduced temperature until it freezes, when it suddenly expands much more. Hence, the degree of the greatest density of water is not that of its greatest coldness; above, or below 39½°, its density diminishes. Dr Hope found that, in any quantity of water, the coldest portion is always at the top, when the temperature is below this point. At higher temperatures water obeys the usual law—the hotter portions are always at the top. Hence it is obvious that ice must be lighter than water, and we accordingly find that it floats upon the surface of that liquid; it is 8 per cent. lighter. Water expands in the act of freezing with extraordinary force: spheres of glass, silver, and gold, have been burst by the freezing of water within them; a sphere of brass, with a cavity of only one inch in diameter, has been thus burst, which was calculated to require, for this purpose, a pressure from within equal to 27,720 pounds. Several metals expand, as they pass to the solid form after fusion, and are therefore employed for casting in moulds, owing to their power of insinuating themselves into all the minute cavities, and so forming a perfect impression of the mould. In liquids, as in solids, the expansion increases in greater degrees than are proportionate to the elevation of temperature. If mercury, on being heated from 32° to 122°, or 90 degrees, expands 14 times, then on heating it to 212°, or 90 degrees more, it expands 15 times more. The expansion of water from 32° to 122° is 4·7; from 122° to 212°, it is 15.

133. *Aëriform bodies* expand much more by heat than liquids, the particles being in less intimate union, and less under the influence of cohesive attraction. The expansion of air is 8 times greater than that of water; that of water, 45 times greater than that of iron. If a bladder partly filled with air be held for some time to the fire, it will appear full; and on cooling, it will shrink to its original bulk. If the neck of a flask, containing same water, be inverted into a basin of water, and the flame of a lamp applied to the large part of the flask, or even the hand applied closely over this part,

the water will be forced out by the expansion of the air within; on removing the source of heat, the water will return into the flask.—All aëriform bodies, if perfectly free from watery vapour, expand *equally* on the application of equal degrees of heat; the rate of expansion is 1-480th part of their whole bulk for every degree of Fahrenheit's thermometer. It has been found that 100 parts of air at 32° expand to 137.5 parts, when heated to 212°; that is, the temperature being raised 180°, the increase in bulk is 37½, which is nearly 1-480th part for each degree. Aëriform bodies differ from solids and liquids, in their expansion being uniform at all temperatures, on the application of the same quantity of heat.

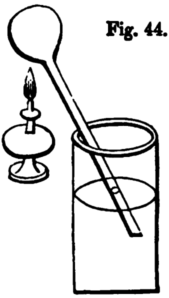


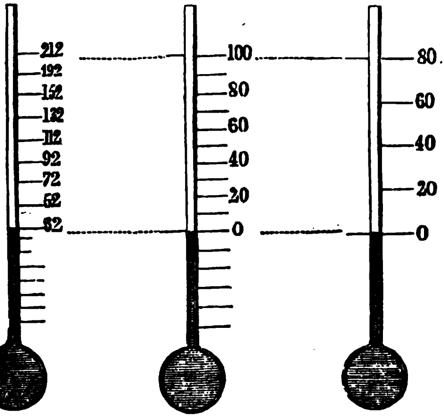
Fig. 44.

THE THERMOMETER.

134. The thermometer is an instrument for measuring the degrees of heat by their effect in the expansion of some body. Solid bodies are not sufficiently expansible to afford indications of temperature; while aëriform bodies, on the other hand, are too much so for common use. Liquids are intermediate in their expansive properties between solid and aëriform bodies, and thus afford very convenient indications of the variations of temperature. The thermometer is merely a glass tube with a bore of very small and regular calibre, having a bulb blown on its extremity; the bulb and part of the tube are filled with mercury, this metal being the most uniform in its expansion at all temperatures. By boiling the mercury, the air is driven out of the rest of the tube, and its extremity is hermetically sealed. A scale marked with degrees is affixed to the tube, and the variations of temperature are indicated by the expansion or rise, by the contraction or fall, of the mercury; and these can be ascertained by simple inspection of the scale. Of the degrees of the scale, there are two, which, under certain circumstances, always present the same phenomena; these are the *freezing* and *boiling points* of water, all the intermediate degrees being arbitrary divisions of the space between these two fixed and unchangeable points. In *Fahrenheit's* thermometer, which is employed in this country, the intermediate space between the freezing and

boiling points of water is divided into 180 parts or degrees, the freezing being marked 32°, and the boiling 212°. This scale was adopted by Fahrenheit from an erroneous supposition that 32 of these divisions below the freezing point of water, which is therefore 0 on his scale, indicated the *zero*, or greatest degree of cold. On discovering his error, he added a series of descending degrees below his zero, prefixing to them the sign —, or minus. The *Centigrade* thermometer was constructed by Celsius, and is employed in France; it consists in an arrangement of the scale, in which the freezing point is marked 0, or *zero*, and the boiling point 100°. In *Reaumur's* thermometer, which is employed in the north of Germany, the freezing point is marked 0, or *zero*, and the boiling point 80°. The degrees are continued of the same size below and above these points, those below being reckoned negative. A figure is added showing the correspondence of the three thermometers. These different modes of graduation are easily convertible: the Centigrade scale is easily reduced to that of Fahrenheit by multiplying by 9, and dividing by 5; that of Reaumur to that of Fahrenheit by dividing by 4 instead of 5; or that of Fahrenheit to either of the others, by reversing the process. Thus:—

Fig. 45.



Cent. 100° × 9 = 900 ÷ 5 = 180 + 32 = 212° Fahr.
Reaum. 80° × 9 = 720 ÷ 4 = 180 + 32 = 212° Fahr.

Or, by reversing the order:—

Fahr. $212^\circ - 32 = 180 \times 5 = 900 \div 9 = 100^\circ$ Cent.
Fahr. $212^\circ - 32 = 180 \times 4 = 720 \div 9 = 80^\circ$ Reaum.

135. Sanctorius invented the *Air Thermometer*, the principle of which may be understood from Fig. 44. This instrument, though more delicate in its indications than those in which mercury or alcohol is used, is affected by the pressure of the atmosphere, independently of temperature, and is therefore seldom used. The *Differential Thermometer* consists of two glass bulbs, connected by a glass tube bent in the form of the letter U. The tube is partly filled with a coloured liquid. On exposing one bulb to heat, the expansion of the air forces the liquid down, and causes it to rise in the opposite part of the tube. This instrument is not intended to indicate the temperature of the atmosphere, as the application of cold or heat to both bulbs at the same time produces no alteration in the level of the liquid; it merely indicates the *difference* of temperature between the two bulbs.

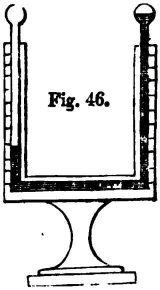
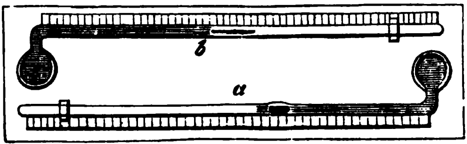


Fig. 46.

136. In *Rutherford's Register Thermometer*, the highest and lowest temperatures which occur within a given time are indicated and made to register themselves. This instrument consists of two thermometers, placed with their tubes in a horizontal position, as shown in the figure. The one *a* contains spirit of wine, the other *b* contains mercury. In the stem of the thermometer *b* a small iron wire, placed at the surface of the mercury, acts the part of an index, being propelled forward as the mercury expands, and being left at the point of greatest expansion, when the mercury contracts; it then indicates the highest temperature which has occurred during an observation. In the stem of the thermometer *a*

Fig. 47.


a small piece of ivory is immersed in the spirit, and by a slight inclination of the instrument is brought to the surface of the liquid. When the temperature falls, the ivory is carried back with the spirit; but, when the temperature rises, the spirit only advances, the ivory being left behind, thus indicating the lowest temperature which has occurred. By inverting the thermometer the ivory is brought again to the surface for a new observation. For measuring high temperatures, a *pyrometer*, Fig. 43, is employed, in which the degree of heat is ascertained by the expansion of a bar of platinum. In Daniell's pyrometer, 1 degree is equal to 7 of Fahrenheit. Metallic thermometers are often employed for indicating ordinary temperatures, by soldering together metals of unequal expansibility: the compound bar bends as the temperature varies, and a scale is attached, and graduated by comparing it with a common thermometer.

137. *Change of Density.*—It follows from the phenomena of expansion by heat and contraction by cold, that the density of bodies is diminished by heat, and increased by cold. If heat be applied to a vessel perfectly full of cold water, the liquid soon flows over; and when the temperature is near the boiling point, the vessel is still full, although the quantity contained in it is less; on cooling, the water sinks below the brim of the vessel. In this case, the heat has driven the particles of water to a greater distance from each other than usual; this is termed the *repulsive* property of heat, and its direct result is to diminish density. Hence, of two equal bulks of water, the one being hot, the other cold, the former weighs the lighter: a pint of boiling water is lighter than a pint of cold water. Spirits are sensibly affected in density by change of season: in the height of summer, spirits will measure 5 per cent. more than in the depth of winter. The following is an interesting experiment in proof of the change of density by temperature: a hollow glass ball may be so prepared that it barely sinks in a vessel of water at the temperature of 60 degrees; on pouring iced water into the vessel, the water becomes denser, and the ball rises to the surface by its comparative lightness; if hot water be added, the ball sinks; and it may thus be made to rise and sink alternately. Heat, therefore, lessens the cohesion which subsists among the particles of bodies, and promotes their repulsion; cold, on the contrary, lessens the

repulsion, and promotes their cohesion; in both cases there is change of density.

LIQUEFACTION.

138. Having considered the effects of heat upon the bulk of bodies, we proceed to consider its effects upon their *form*. The forms of bodies, as they exist in nature, are three; viz. the solid, the liquid, the aëriform. It is supposed that these states depend upon varieties of temperature,—that every solid may become liquid, and every liquid aëriform, upon the application of different degrees of heat. The former of these effects is that of the *conversion of solids into liquids.*—Solids melt at very different temperatures, as may be seen by the following table:—

Lead	melts at 612°	Olive oil	melts at 36°
Bismuth	476	Ice	32
Tin	442	Milk	30
Sulphur	232	Wines	20
Wax	142	Oil of turpentine	14
Spermaceti	112	Mercury	—39
Phosphorus	108	Liquid ammonia	—46
Tallow	92	Ether	—46

During the conversion of a solid into a liquid, heat is absorbed from surrounding bodies. This fact may readily be ascertained by placing a thermometer in a vessel containing common salt and water; the salt, in melting, absorbs heat from the water, and the temperature falls considerably. Upon the same principle, cream may be frozen, when placed in tin vessels and surrounded by pounded ice and salt; the liquefaction of these two solids deprives the cream of its heat, so that its temperature is reduced below the freezing point. Hence it may be stated, that *freezing is a warming process*, and *melting a cooling process:* by the freezing of large bodies of water, heat is given out, and the atmosphere is warmed; by the melting of ice and snow, heat is absorbed, and the atmosphere cooled.

139. *Latent Heat.*—The quantity of heat absorbed, during the conversion of a solid into a liquid, merely serves to melt it, without raising its temperature in the least degree. If a mass of ice be introduced into a warm room, and a thermometer be applied to it, the temperature of the ice continues to rise till the thermometer stands at 32°; it there

remains stationary, although heat is continually entering into the melting ice, as before; and it remains so until the whole of the ice is melted; the thermometer then continues to rise, until it indicates the temperature of the room. Hence, it requires much more time and fuel to procure a vessel of boiling water from ice, than from water itself at the same temperature as the ice. The heat absorbed during the change from the solid to the liquid form, is termed insensible or *latent*, from its not affecting the thermometer. The absorption of heat during a change of form in bodies, without raising the temperature of the absorbing body, is proved by the interesting experiments of Dr Black. If a pound of water at 32° be mixed with a pound of water at 172°, the temperature of the mixture will be intermediate between them, and will therefore stand at 102°. But if a pound of ice at 32° be mixed with a pound of water at 172°, the temperature of the mixture will not be intermediate, as before: the ice melts, and the result is two pounds of water at 32°; that is, 140 degrees of heat have passed from the water into the ice, without raising its temperature a single degree; they merely sufficed to melt it. The quantity of latent heat, therefore, which water possesses, is 140 degrees; or, in other words, the difference between a pound of water at 32° and a pound of ice at 32°, is that the former contains, in a concealed state, as much more heat than the latter as would suffice to heat another pound of water 140 degrees. Heat, therefore, exists in two different states: it is either free, sensible, and affects the thermometer; or it is combined, latent, and has no effect upon the thermometer. All heat is sensible, if it be considered in reference to bodies of which the *form is permanent.* Dr Black, who first noticed this fact, observes that, if only a small addition of heat were required to change ice into water at 32°, the consequences would be tremendous: masses of ice and snow would melt with rapidity, causing torrents and inundations which would sweep every thing away before them; but these masses melt with extreme slowness, sometimes requiring several weeks of warm weather for their complete liquefaction. It is owing to the same slowness of liquefaction, that ice is preserved in summer in ice-houses. The same principle applies to the conversion of other solids into liquids, though the quantity of heat required to effect the change varies with different solids. Thus, of equal weights of the following bodies, the degrees of heat required to melt them, and hence called their *Caloric of fluidity*, are as follow: spermaceti, 145°; lead, 162°; bees-wax, 175°; zinc, 493°; tin, 500°; and bismuth, 550°.

140. The heat which remains latent in water so long as it is in the liquid state, is liberated and rendered sensible when the water freezes. This may be proved in several ways. 1. As a quantity of heat enters into the ice to convert it into water, it is obvious that, in the contrary process, this heat must be disengaged in order that the water may be reconverted into ice. Accordingly we find that a considerable time is occupied in the congelation of a mass of water; that the heat which is being liberated is not sensible in the ice, the temperature of which is not higher than that of the water: and that the liberated heat is actually sensible in the air, more and more of which is being successively *raised* to 32°. 2. The following is a more decided proof. Water may be cooled down many degrees below 32° without freezing, provided it be kept perfectly still. Dr Thomson cooled it as low as 5°. If it be cooled down to this temperature, and a tremulous motion be then communicated to it, congelation is determined, a large portion of it is suddenly converted into ice, the latent heat of which is liberated in such quantity as to raise the temperature of the whole mass suddenly to 32°. 3. The liberation of heat, upon the conversion of a liquid into a solid, may be illustrated by the slaking of lime: when water is poured upon lime, it unites with it, and much heat is evolved; buildings have sometimes taken fire in consequence of water having been accidentally brought into contact with lime. 4. Another illustration of this principle occurs when a little sulphuric acid is added to a small quantity of muriate of lime in a wine glass; both these substances are liquid, but they unite and form a solid substance, and, as they unite, so great a quantity of heat is evolved, that the glass is almost too hot to be held in the hand.

141. The rapid absorption of heat which bodies exhibit in passing from the solid to the fluid state, explains the operation of *freezing mixtures*. 1. If nitre be dissolved in water, the temperature of the liquid falls above 16 degrees. 2. If five parts of nitre and five of sal ammoniac, both finely powdered, be dissolved in nineteen parts of water, the temperature may fall from 50° to 10°, or 22 degrees below the freezing point. 3. If *snow* and a third of its weight of common

salt be mixed together, they become liquid, and the temperature of the mixture may fall to 0°. These phenomena depend upon the affinity which exists between these salts and water; in order to satisfy this affinity the bodies melt, and in so doing absorb heat, which becomes latent in them, from surrounding bodies. By this means, considerable degrees of cold may be produced; the degree of cold depends on the quantity of heat which passes from a free to a latent state; and this, again, depends on the quantity of the substance liquefied, and the rapidity of the liquefaction. Artificial processes for producing cold, as in the preparation of ices for desserts in summer, are conducted on this principle. Mercury has been frozen by means of a mixture of snow and nitric acid.

VAPORISATION.

142. The second general effect of heat upon the *form* of bodies, is the *conversion of solids and liquids into vapour.* Vapours are light, expansible gases, capable of being condensed by cold into liquids or solids, as in the case of steam.

143. *Evaporation.*—The most familiar instances of the conversion of liquids into gases, are those of *Evaporation*, a process attended by the absorption of heat, and the consequent production of cold. *Spontaneous Evaporation* denotes the formation of vapour by some natural agency, without the direct application of heat. This process is continually going on at the surface of the earth and of the ocean, and the vapour thus produced is returned in the form of rain, snow, &c. Different liquids vary considerably in the rapidity with which they evaporate; it is found, generally, that those liquids whose boiling points are lowest, evaporate most rapidly; ether, for instance, evaporates much more rapidly than water. The comparative rapidity with which these two liquids evaporate, may be estimated by the cold they respectively produce during evaporation. The following are examples of evaporation at ordinary temperatures:—1. If strong ether be poured upon the hand, it presently disappears, and a strong sensation of cold is produced; the ether itself is not cold, but it withdraws heat from the hand as it passes off in the form of vapour. When our clothes have been wetted by a shower of rain, we experience cold, which is less intense, owing to the evaporation of water being less rapid than that of ether. 2. If a thermometer be immersed

in ether, no change of temperature is indicated; but on withdrawing the thermometer, the mercury falls, owing to evaporation from the bulb. 3. If the bulb be wrapped round with muslin, and immersed in ether, and then withdrawn, the mercury falls still lower on the application of warm air from the breath. 4. The contents of the bulb may be reduced many degrees below freezing, by continually wetting the bulb with ether, and blowing on it with a pair of bellows. 5. The watering of streets in cities, during hot weather, not only prevents the dust from rising, but has a very sensible effect upon the atmosphere, which becomes cooled from parting with heat—to promote the evaporation of the water. 6. Upon the same principle of evaporation, porous vessels are constructed as coolers for wine; they are soaked in water, which, by its evaporation, cools whatever is contained within them. 7. Water passes into vapour very rapidly in a vacuum, and a proportionate degree of cold is produced. Hence, Leslie contrived to freeze water by the cold produced by its own evaporation, within the exhausted receiver of an air-pump. The water was placed in a porous cup, over a glass plate containing sulphuric acid, which absorbs the vapour as fast as it is formed. 8. In Wollaston's *Cryophorus*, water is frozen by its own evaporation. This instrument consists of two hollow glass balls, connected together by a bent glass tube, and one of them containing some water, as represented in the figure. The air is expelled by boiling the water, and the instrument is hermetically sealed by fusing the projecting point at *e*. If the empty ball be now placed in a freezing mixture of salt and snow, the vapour it contains is instantly condensed, and its place supplied by vapour from the other ball. Thus, a rapid evaporation takes place in one ball, and condensation in the other, till the water in the former one freezes. The term Cryophorus, or *frost-bearer*, is derived from this transference of cold from one ball to the other. 9. A temperature of —135° has been produced by the evaporation of liquid carbonic acid; one portion of the liquid is frozen by evaporation of the other portion. 10. Lastly, evaporation is constantly taking place from the surface of our bodies;

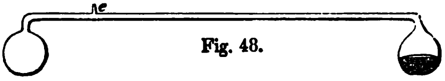


Fig. 48.

the quantity of perspiration and of heat carried away being proportionate to the violence of the exercise we undergo. In this manner the equilibrium of animal temperature is maintained during health. When the natural evaporation is checked by disease, the temperature of the body rises, and fever ensues.

144. The chief *circumstances which influence Evaporation*, are, extent of surface; and the condition of the atmosphere, in respect to temperature, dryness, and motion. 1. The rapidity of evaporation is proportionate to the extent of the evaporating surface: a given quantity of water will evaporate four times as rapidly from a surface of two feet square, as from one of a foot square. 2. Liquids evaporate more rapidly in warm, than in cold situations, the rapidity of evaporation being proportionate to the degree of temperature. 3. Liquids evaporate more rapidly in a dry, than in a damp, atmosphere; even in cold seasons, if the air is dry, evaporation goes on rapidly, while in warm seasons it is comparatively slow, if the air is charged with moisture. 4. The motion of the air, or wind, promotes evaporation, by removing the portions of vapour as they are successively formed from the evaporating surface; hence, the process is more rapid in the open air than in a confined place, and is particularly promoted by the prevalence of a strong wind. Evaporation takes place from the surface of water at all temperatures, however low. The atmosphere must be, therefore, supposed always to contain some moisture, the presence of which may be readily ascertained on bringing a glass of very cold water into a warm apartment: the outside of the vessel is presently covered with *dew*, which is condensed from the surrounding air.

145. *Hygrometer.*—The condition of the air with regard to moisture is indicated by an instrument called a *hygrometer*. The quantity of moisture present in the air is inferred from the reduction of temperature required to produce a deposition of dew from the air; the less the reduction of temperature required, the greater the amount of moisture in the air. *Daniell's dew-point hygrometer* is constructed upon this principle, and is generally used at present. This instrument consists of two balls, connected together by a tube bent in the form of a siphon, as represented in the figure. The ball *b* contains some ether, from which the air has been expelled in the same manner as in the cryophorus. A thermometer

is placed in this arm of the siphon tube, and its bulb descends into the ball. A zone of the ball is gilded and burnished, in order that the dew deposited upon it may be visible. The other ball *a* is covered with muslin, which is kept moist by constantly dropping ether upon it. The evaporation of the ether from the ball *a* condenses the vapour from the ball *b*, the temperature of which is gradually reduced till dew is deposited upon the burnished part of the ball. The degree at which the deposition takes place is indicated by the enclosed thermometer; this degree is called the *dew-point.* As the temperature of the ball *b* is allowed to rise, the disappearance of the dew takes place at about the same point; the mean point between its appearance and disappearance will strictly indicate the dew-point. The thermometer attached to the stem of the instrument is for indicating the temperature of the atmosphere at the time of the observation.

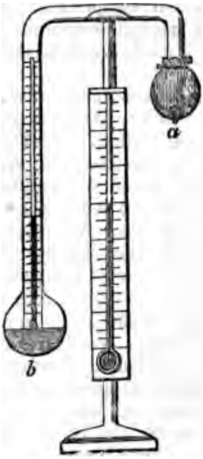


Fig. 49.

EBULLITION.

146. We now proceed to the phenomena of Vaporisation, as it occurs at *high* temperatures, and of which the formation of *Steam* furnishes a good example. If heat be applied to ice-cold water in an open vessel, a thermometer, placed in it, gradually rises till it reaches the temperature of 212°, where it remains stationary, and no addition of heat will raise it a degree higher. A new process now begins. Bubbles are formed at the lower part of the vessel, rise to the surface, and escape with agitation in the form of *Steam;* this constitutes *Ebullition*, or the boiling, of water. Steam is a vapour consisting of particles of water, which expand so forcibly, that one cubic inch of water, when converted into steam, expands into 1694 cubic inches. Steam, as it rises from water at 212° exhibits the same phenomenon as occurs in ice when heated at the temperature of 32°—a quantity of

heat is absorbed, which serves only to change the *form* of the body, in this case converting water into steam, as in the former it converted ice into water—in both cases being termed insensible or *latent*. A much larger quantity of heat is absorbed during vaporisation than during liquefaction: the latent heat of water is 140, that of steam is 1000; that is, during the conversion of water into steam, sufficient heat is absorbed to raise the temperature of an equal quantity of water 1000 degrees. From the foregoing facts we learn that liquids can never become hotter, in open vessels, after they have been made to boil; that the prolonged application of a moderate heat will raise a liquid to the same temperature as the most intense heat; and that, when water has once reached the boiling point, it may be preserved at that temperature by a moderate degree of heat. The quantity of heat which becomes latent during vaporisation, varies with the temperature at which this takes place; *the more elevated the temperature, the less is the latent heat.* Thus, the latent heat of steam at 212° is 1000; but that of steam formed at 112°, a process which readily takes place in a vacuum, is 1100; and at 312° it is only 900. Hence there is no economy of fuel by distilling at low temperatures in a vacuum. The steam produced at 112° is much more expanded and rare than that produced at 212°, and has a greater heat. It has been shown by Mr Sharpe, of Manchester, that, whatever be the temperature of steam, from 212° upwards, if the same weight of it be condensed by water, the temperature of the water will always be raised the same number of degrees; or, the latent and sensible heat of steam, added together, amount to a constant quantity.

147. When steam is reconverted into water, the *latent* heat is given out. Hence, a gallon of water in the form of steam, when added to cold water, will impart more heat to it than a gallon of water at the same temperature as the steam; one part of water, for instance, at 212° will raise the temperature of 100 parts of water at 50° only 1½ degree, whereas one part of water in the form of steam will raise 100 parts of water 11 degrees. In consequence of the large quantity of heat contained in steam, it is used with advantage, on many occasions, to heat large quantities of fluids without the direct application of fire.

ATMOSPHERIC PRESSURE.

148. The temperature at which liquids boil depends on the degree of *Atmospheric Pressure* to which they are subjected. The atmosphere is supposed to extend about forty-five miles in height; it presses with a weight of fifteen pounds on each square inch of the surface of the earth, and upon a man of common stature with a weight of fifty tons. We should therefore expect that liquids would boil at lower degrees of temperature, as we ascend higher from the surface of the earth, the pressure of the atmosphere being greatest at the level of the sea, and proportionably less as the ascent is greater. And so it is. Water boils at a lower temperature on the tops of mountains than at their bases; on the top of Mount Blanc, Saussure found that water boiled at 184°, whereas in mines or deep pits the boiling point is higher than upon the surface of the earth. An ascent of 530 feet causes the boiling point to be lowered one degree of temperature. When it is said that 212° is the boiling point of water, it is always understood that the atmospheric pressure, as indicated by the barometer, is equivalent to a column of mercury of 29·8 inches. For every inch by which the barometer varies from this height, the boiling point of water varies 1·76 degree. The following are the variations between the atmospheric pressure as indicated by the inches of mercury in the barometer, and the boiling point of water:—

Inches of mercury in Barometer.	Water boils at
27·74	208°
28·29	209
28·84	210
29·41	211
29·8	212
30·6	213

149. When the *atmospheric pressure* is removed, liquids boil at a temperature of about 145 degrees below their usual boiling point. If hot water, with a thermometer in it, be placed under the receiver of an air-pump, the water boils, and the temperature falls, as the air is being exhausted; as the water receives no heat from without, a portion of its sensible heat is employed in effecting the change of form. Water boils in a good vacuum at 67°. Ether boils rapidly in the receiver of an air-pump, as this is exhausted. At

ordinary temperatures, ether is much above its boiling point, when freed from the atmospheric pressure; as the pressure diminishes, the boiling increases, and much cold is produced, a portion of the heat of the ether being absorbed during its change of form. If water in a tube be placed in the ether, the former will freeze, while the latter boils. Mercury may be frozen in the same manner.—In the absence of an air-pump, the same principle may be illustrated by the following experiment. Some water is made to boil in a glass flask over a lamp; the flask is then closed with a cork, while the upper part is filled with steam, and it is removed from the lamp. When the boiling has ceased, it may be renewed on plunging the flask into cold water, and, the colder the water is, the brisker will be the ebullition. On removing the flask from the cold water and plunging it into warm water, the boiling again ceases. It may be again renewed on again immersing the flask in cold water. In this experiment, the boiling ceases, on corking the flask, owing to the pressure exerted by the confined steam on the surface of the water; on plunging the flask into cold water, this steam is condensed, and the water again boils under the reduced pressure; on immersing the flask in hot water, the steam is no longer condensed, and by its pressure it prevents the boiling of the water. The variation of the boiling point from pressure is made subservient to practical purposes. It is often applied to the evaporation and concentration of solutions likely to be injured if subjected to a high temperature. This principle is applied to the manufacture of sugar, the syrup of which might be injured, if boiled at high temperature.

150. The boiling point of liquids appears to vary, to a certain degree, from other circumstances. It was observed by Gay-Lussac that water boils at a temperature of two degrees higher in glass than in metal, so that, whan water in a glass vessel has ceased to boil, the boiling may be renewed on introducing into the water a twisted piece of cold iron wire. Gay-Lussac also observed that liquids pass into vapour more readily when in contact with angular and uneven surfaces, than when these are smooth and polished. It has been also remarked that, if oil be present with water, the boiling point is raised a few degrees, in any kind of vessel. A powder thrown into heated liquids promotes the discharge of vapour.

151. There is a curious phenomenon connected with ebullition, which requires to be noticed. If a few drops of

water be thrown upon a metallic cup, which is at a higher temperature than that of boiling water, the hotter the cup is, the *less* rapidly does the water boil away. The explanation of this fact, usually given, is as follows:—At low temperatures, water exhibits an attraction for the surfaces of solids, spreads over them, is thus brought into close contact with them, and thereby facilitates the communication of heat from them. But at high temperatures, the repulsive power of heat, already noticed, appears to exert so decided an influence, that the attraction between the heated metallic surface and the water ceases to exist; the water consequently does not spread over it, is not rapidly heated, and therefore boils off slowly. The following appears to be a more satisfactory explanation. At low temperatures, the drop of water spreads over the surface, and comes in contact with it, so as to evaporate rapidly; but at high temperatures, the lower portion of the drop is immediately converted into vapour as it approaches the heated surface; the remaining portion of the fluid is buoyed up by this vapour, and does not come into contact with the hot surface at all; it floats, as it were, upon an atmosphere of steam, and retains its globular form. A drop of water, allowed to fall upon dust or any fine powder, exhibits a similar form. A familiar method of judging of the heat of the smoothing iron, employed in the laundry, is founded on the same principle: a drop of saliva is allowed to fall upon the iron; if the drop run along the surface of the metal, the iron is considered sufficiently hot; if, on the contrary, the drop adheres and is quickly dissipated, the temperature of the iron is considered too low.

152. *Elasticity of Steam.*—Steam, as formed from water, is invisible; the *appearance* of steam is caused by its condensation into vesicles, or minute drops, when mixed with cold air. The temperature of steam, formed in open vessels, is always 212°, or the same as that of the water which produces it. When confined, or subjected to pressure, it rises in temperature, and acquires great elastic force; it is then called *high-pressure steam.* It is remarkable that, whereas steam arising from boiling water in open vessels produces a severe scald of the hand when applied to it, that which is produced from water under pressure, though of a much higher temperature, causes no painful sensation of the hand when exposed to it, as it issues into the air. This result is owing to the great expansion which high-pressure steam undergoes as it

escapes into the air; it mixes with several times its weight of air, its temperature falls considerably below 212°, and is consequently much lower than that of ordinary steam.—The amount of expansion attending vaporisation differs considerably in different liquids. Water expands to 1694 times its volume, from its point of greatest density, alcohol to 659, and ether to 443, the barometer being at 29·92, and the temperature at 212°. Hence, some liquids, which are lighter than water and more volatile, produce heavier vapours, from their inferior power of expansion during vaporisation. The greater the pressure, the more elevated is the temperature required to produce vapour, the denser is the vapour produced, and the greater its elasticity. At 212°, the barometer standing at 30 inches, steam has sufficient elasticity to overcome the atmospheric pressure, and rise against it. The elasticity of steam still in contact with water, increases in a greater ratio than the temperature at which it is produced: thus, at 212° it is equal to one atmosphere; at 250·5, to two atmospheres; at 293·7, to four; at 341·78, to eight; at 398·48, to sixteen; at 435·56, to twenty-four. To this rapidly increasing elasticity are owing the frequent explosions of vessels not provided with safety-valves.

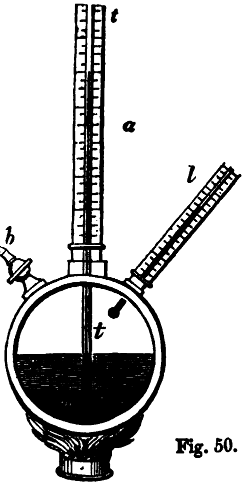


Fig. 50.

153. The *elastic force of steam*, when heated under pressure, may be illustrated by the annexed figure, which represents a stout copper vessel, of a globular form, called a *Papin's Digester*. It contains some mercury *m*, and water *w*; and a long glass tube *t t*, open at both ends, is fastened into it, the lower extremity dipping into the mercury, and the upper part being furnished with a scale *a*, divided into inches. There are two openings in the vessel; into one of these a stopcock *b* is screwed, and into the other a thermometer *l*, the bulb of which is within the vessel. Heat is applied, the stopcock being open, until the water boils. On closing the stopcock, and continuing

the heat, the temperature within rises above 212°, as indicated by the thermometer. Steam continues to be formed, and, becoming denser, forces the mercury up in the tube *t t* to a height proportional to the elastic force of the steam. The weight of the atmosphere being equal to a column of mercury of 30 inches, this pressure has been overcome by the steam at 212°, before the mercury began to rise in the tube *t t*. For every thirty inches, therefore, which the mercury rises in this tube, the steam is said to have the elastic force of another atmosphere. Thus, if the mercury rise 30 inches, the elastic force of the steam is that of two atmospheres; if it rise 45 inches, it is that of two atmospheres and a half; if 60 inches, of three atmospheres; and so on.

154. *Condensation of Steam.*—It has been stated, that during the formation of steam from water at 212°, and under the ordinary atmospheric pressure, 1000 degrees of heat are absorbed, which serve merely to change the *form* of the body; and that, as a consequence of this, one cubic inch of water expands into 1700 cubic inches of steam. We should, therefore, expect that, upon withdrawing this heat, the form of the body would again be changed, or, in other words, that the steam would be *condensed* into water. And such is the case. When any body which is colder than steam is brought into contact with steam, the latter gives out its latent heat, till the temperature of the cold body becomes the same as that of the steam, or till the whole quantity of steam is condensed to a degree of elasticity corresponding to the temperature to which the cold body is raised by the heat of the steam. In order to produce effective and rapid condensation, several circumstances are required, viz., a large quantity, a great degree of coldness, and a rapid conduction of heat, of the cold body employed for condensation. The greater the quantity of the cold body, the less will its temperature be raised; and the colder it is, the more will the elastic force be reduced; hence, in order to reduce the elastic force of steam as low as possible, the quantity and coldness of the cooling body should be as great as possible. The most effective cooling body for condensation, is *water*. Its operation may be illustrated as follows. If the cubic foot of steam, formed from the cubic inch of water at 212°, as already described, be received into a vessel which just contains it, and 5½ cubic inches of water at 32° be injected into the vessel, the steam will immediately communicate its latent

heat to the cold water, and will itself return to the liquid form. The vessel will then be found to contain 6½ cubic inches of water at 212°; of these, 5½ have been raised from 32° to 212°, by the latent heat of the steam, and the remaining inch retains the temperature which it had when in the form of steam. These results agree with those above described, as taking place in the production of steam from water. In order to convert a given quantity of water at 212° into steam, it required 5½ times as much heat, as was required to raise the same quantity of water from the freezing to the boiling point. Reversely, during the reduction of steam to water, the former parts with as much heat as is sufficient to raise 5½ cubic inches of water from 32° to 212°; that is, 5½ times 180°; that is, 900°, or the latent heat of steam.

155. *Production of a Vacuum.*—The condensation of steam, just described, is obviously attended by the important result of producing a *vacuum.* A cubic foot of steam contains 1728 cubic inches; when this quantity of steam is condensed, one inch of water is found in the containing vessel, while 1727 inches of it remain unoccupied; in other words, the vessel, with the exception of one cubic inch of water, presents a vacuum. This may be illustrated by a simple experiment. If a little water or ether be put into a glass tube, open at one end, and blown into a bulb at the other, and the bulb be held over the flame of a candle, the liquid will boil, and the steam issue copiously from the tube. If the tube be now inverted, and its open end be plunged under cold water, the steam in the tube will be condensed, and the water will be forced up suddenly into the tube, and fill the bulb. It is a law in physics, that, when a vacuum is produced, the surrounding bodies have a tendency to rush into it with a certain force. The production of a vacuum becomes, therefore, a source of considerable mechanical power.

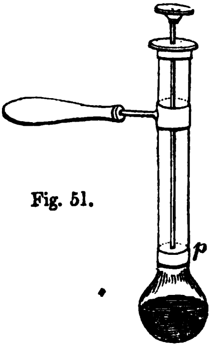


Fig. 51.

156. *Mechanical Force produced by the preceding operations.*—The application of the foregoing principles, as a moving power in the Steam Engine, may be illustrated by a little

instrument contrived by Wollaston. It consists of a glass tube, Fig. 51, enlarged at one end into a bulb, and open at the other. A piston p is fitted to this tube, so as to move up and down with ease, but at the same time to be air-tight. Some water is put into the bulb, and heated; steam is formed, and the piston is raised to the top of the cylinder. In this case, *the elastic force of the steam* is the moving power, and this force is proportionably greater, as the piston is more loaded, and the steam more confined. If the bulb be now plunged into cold water, the steam in the cylinder is condensed, and a vacuum is produced below the piston, which is now forced down to the bottom of the cylinder by the pressure of the atmosphere. In this case, the moving power is acquired by *the condensation of the steam*, and the consequent production of a vacuum; and this is the principle of the common condensing engine.

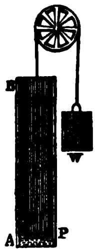


Fig. 52.

157. The *amount* of mechanical force which may be produced by the foregoing processes, may be easily estimated. 1. Let us suppose the water A in the tube A B, in the adjoining figure, to occupy the space of a cubic inch, and the surface of the piston P to be an inch square; if the weight of the piston be exactly counterbalanced by a weight W acting over a pulley, it is evident that the force of the atmosphere alone will act on the upper part of the piston, and that this force will be equal to a weight of fifteen pounds. It has been already stated that a cubic inch of water expands into 1700 cubic inches of steam; hence, the piston would be raised this number of inches in the tube, provided the latter were of sufficient length; or, in other words, *the mechanical force produced by the evaporation of a cubic inch of water is sufficient to raise a weight of fifteen pounds to a height of* 1700 *inches, or* 142 *feet.* 2. It is evident that, to raise fifteen pounds to a height of 142 feet, is the same thing as to raise 142 times fifteen pounds, that is, 2130 pounds, or nearly a ton weight, to a height of 1 foot; and, hence, it may be stated, in round numbers, that *the mechanical force produced by the evaporation of a cubic inch of water, is sufficient to raise about a ton weight to the height of one foot.* 3. Let us now suppose the piston to be loaded with another weight of fifteen pounds, so as to be acted upon by a pressure equal to that of two atmospheres. The results would be, that a temperature of

about 250° would be required to convert the water into steam, and that the piston would be raised to 72 feet, or little more than half its former height. In this case, the mechanical force would be sufficient to raise double the former weight to half the former height. And it may be stated, generally, that the height to which the piston would be raised, would be diminished in a proportion somewhat less than that in which pressure on the piston is increased.

158. *Economical Applications of Heat.*—The following cases, in which the application of heat, evolved by the economy of fuel, is made subservient to practical purposes, are copied from the last edition of Dr Lardner's Treatise on the Steam Engine:—

(1.) A pint of water may be evaporated by two ounces of coals. In its evaporation it swells into two hundred and sixteen gallons of steam, with a mechanical force sufficient to raise a weight of thirty-seven tons a foot high. The steam thus produced has a pressure equal to that of common atmospheric air; and by allowing it to expand, by virtue of its elasticity, a further mechanical force may be obtained, at least equal in amount to the former. A pint of water, therefore, and two ounces of common coal, are thus rendered capable of doing as much work as is equivalent to seventy-four tons raised a foot high.

(2.) The circumstances under which the steam engine is worked on a railway are not favourable to the economy of fuel. Nevertheless a pound of coke burned in a locomotive engine will evaporate about five pints of water. In their evaporation they will exert a mechanical force sufficient to draw two tons' weight on the railway a distance of one mile in two minutes. Four horses working in a stage coach on a common road are necessary to draw the same weight the same distance in six minutes.

(3.) A train of coaches weighing about eighty tons, and transporting two hundred and forty passengers with their luggage, has been taken from Liverpool to Birmingham, and back from Birmingham to Liverpool, the trip each way taking about four hours and a quarter, stoppages included. The distance between these places by the railway is ninety-five miles. This double journey of one hundred and ninety miles is effected by the mechanical force produced in the combustion of a quarter of a ton of coke, the value of which is six shillings. To carry the same number of passengers daily between the same places by stage coaches on a common road, would require twenty coaches and an establishment of three thousand eight hundred horses, with which the journey in each direction would be performed in about twelve hours, stoppages included.

(4.) The circumference of the earth measures twenty-five thousand miles; and if it were begirt with an iron railway, such a train as above described, carrying two hundred and forty passengers, would be drawn round it by the combustion of about thirty tons of coke, and the circuit would be accomplished in five weeks.

(5.) In the drainage of the Cornish mines the economy of fuel is much attended to, and coals are there made to do more work than elsewhere. A bushel of coals usually raises forty thousand tons of water a foot high; but it has on some occasions raised sixty thousand tons the same height. Let us take its labour at fifty thousand tons raised one foot high. A horse worked in a fast stage-coach pulls against an average resistance of about a quarter of a hundred weight. Against this he is able to work at usual speed through about sixteen miles daily: his work is therefore equivalent to one thousand tons raised one foot. A bushel of coals consequently, as used in Cornwall, performs as much labour as a day's work of fifty such horses.

(6.) The great pyramid of Egypt stands upon a base measuring seven hundred feet each way, and is five hundred feet high, its weight being twelve thousand seven hundred and sixty millions of pounds. Herodotus states, that in constructing it, one hundred thousand men were constantly employed for twenty years. The materials of this pyramid would be raised from the ground to their present position by the combustion of about four hundred and eighty tons of coals.

(7.) The Menai Bridge consists of about two thousand tons of iron, and its height above the level of the water is one hundred and twenty feet. Its mass might be lifted from the level of the water to its present position by the combustion of four bushels of coal.

159. *Incandescence.*—Many bodies become *luminous*, when exposed to high temperatures. Solids and liquids appear red in the dark, when heated to 800° or 810°; a temperature of 980° is requisite to produce this effect in day-light. This luminous state of bodies is termed their *incandescence*, and it takes place in all bodies, which are capable of it, at the same

temperature. This effect, as it occurs in solids and liquids, is perfectly independent of combustion. Gases do not become incandescent at any temperature, unless in a state of combustion; yet they may be rendered so hot, that solids placed in them become immediately incandescent. Incandescent bodies are at first of a dull-red colour, which passes into an orange tint, and eventually assumes a shining white appearance.

SPECIFIC HEAT.

160. All bodies do not contain the same quantity of heat at the same temperature, nor can they be raised to the same temperature by communicating to them the same amount of heat. 1. If equal quantities of heat be applied to water, to oil, and to mercury, for every degree of temperature which the water acquires, the oil will acquire two, and the mercury twenty-three, degrees. 2. If a bar of iron and a bar of copper, of equal bulks, be both plunged into boiling water, they will eventually become equally hot, but they will have absorbed unequal quantities of heat to raise them to an equal temperature. 3. In heating a pound of mercury, and a pound of water, up to the same temperature, in vessels placed in a hot water bath, the mercury will be found to reach the required temperature in half the time occupied by the water for this purpose; and, on removing these liquids, when equally heated, the mercury will cool twice as rapidly as the water. The mercury absorbs only half as much heat as the water, in reaching the same temperature, and, consequently, has only half as much heat to part with on cooling. 4. If equal weights of water at 40°, and of mercury at 160°, be mixed together, the resulting temperature of the mixture is 45°; in this case, the mercury has parted with 115 degrees, which have raised the temperature of the water only 5 degrees. From these and similar facts it has been concluded, that equal bulks of dissimilar bodies require unequal degrees of heat to raise them to the same temperature; and that, if equal quantities of heat be made to enter different bodies, they will raise them to different temperatures. This property of bodies is termed their *capacity* for heat; and the quantity of heat required by each body in order to raise it to a certain temperature, is called its *specific heat.* It has been found, by experiment, that a pound of water absorbs thirty times more heat than a pound of mercury, in being raised to the same temperature;

in other words, the capacity of water for heat is thirty times greater than that of mercury. The following are the specific heats of several substances, chiefly according to the late experiments of Regnault:—

Water	1,000	Nickel	109
Alcohol	660	Cobalt	107
Ether	520	Zinc	095
Nitric acid	442	Copper	095
Sulphuric acid	333	Silver	057
Sulphur	202	Tin	056
Phosphorus	188	Platinum	032
Iron	114		

Of all bodies, solid or liquid, water has the greatest capacity for heat. But the capacity of *steam* for heat is less than that of an equal weight of water, being only 847; hence we learn, that the specific heat of a body varies with its physical state.

161. The *capacity of bodies for heat* appears to be, generally, in inverse ratio to their specific gravities. The capacity of water to mercury is as 29 to 1, its specific gravity is as 1 to 14. The capacity of hydrogen is 12 times greater than that of an equal bulk of atmospheric air, though the air is about 13 times heavier than the gas. Hydrogen, the lightest of all bodies, has the greatest capacity for heat; while the metals, the heaviest of all bodies, have the least.—When any substance undergoes *increase in bulk*, its density is diminished, and its capacity for heat increased. If water be thrown upon the bulb of a thermometer, it assumes the form of vapour; its bulk being thus increased, its capacity for heat is also increased, and it derives heat from the mercury, which consequently falls. When aëriform bodies are relieved from pressure, as in the exhausted receiver of an air-pump, at the tops of mountains, or as they escape from vessels in which they have undergone pressure, they expand, their capacity for heat increases, and their temperature falls. On the other hand, when aëriform bodies are compressed, their capacity for heat is diminished, heat is liberated, and their temperature rises. Hence, a change of capacity, without a change in the quantity of communicated heat, is accompanied by a change of temperature.—That bodies contain a large quantity of *latent* heat, is proved by the following facts. 1. It has been already noticed that a piece of cold iron may be hammered till it becomes red hot; this effect is

owing to the evolution of heat, which, while latent, only tended to give the iron malleability and ductility, but which, when liberated, operates with as much activity as if it had never been latent. 2. If a little sulphuric acid be mixed with about an ounce of nitric acid, and the mixture be poured into oil of turpentine, the whole will burst into flame. This is owing to the *compound* having less capacity for heat than its ingredients, separately; consequently, a portion of their heat is liberated, and produces inflammation. Gay-Lussac contrived an apparatus for ascertaining the specific heat of different bodies, by means of which a hot current of one gas met a cold current of another gas, in the centre of a small reservoir, in which a thermometer was placed. The temperature of each gas was ascertained by a thermometer before they met. Thus, by knowing their temperature before, and after, their union, their respective capacities for heat are determined.

QUESTIONS ON CHAP. II.

113. By what principle in nature is the attraction of cohesion counteracted? What is the general tendency of Heat? Explain the doctrine of *equilibrium* in regard to heat. What is meant by caloric? Give an instance of the effect of heat in changing the form of a body.—114. What are the principal sources of heat? By what means may intense heat be procured from the rays of the sun? What calorific effects may be produced by electricity? Give a familiar instance of the production of heat by chemical action. Explain the phenomenon of animal heat. By what mechanical operations may heat be evolved? What is the cause of the evolution of heat, attendant on percussion? Give some familiar instances of the production of heat by friction. What amount of heat is evolved in the process of boring a cannon? What heating effect may be produced by condensation?

115. How is heat communicated between bodies in contact, and between the contiguous parts of the same body?—116. What is meant by conduction of heat?—117. To what bodies is the conduction of heat chiefly confined? Give a familiar illustration of conduction of heat in solid bodies. What bodies are good conductors? Give some examples of conduction. Is there any relation between the conducting power of solid bodies, and their

density? Prove your statement. What is the comparative conducting power of different metals? Trace the comparative conducting powers of other substances. Why is snow a protector against cold? Give an instance of the non-conducting power of sand.—118. Explain the principle upon which woollen substances are selected for clothing. What is the conducting power of spun silk, as compared with that of raw silk? of cotton wool, as compared with hare's fur?—119. What discovery was made by Mr Trevelyan respecting the communication of heat between metals? Explain the cause of this phenomenon.—120. Are liquid bodies good conductors of heat? What experiments have been made with the view of ascertaining the conducting power of liquids? Show, by explanation of Fig. 38, that what is called conduction in liquids, is rather an act of *conveyance*. Do liquids convey better, in proportion to their greater density? Give examples in proof of this.—121. How is heat diffused among aëriform bodies? State the comparative capabilities in the human body, of supporting heat, as communicated to it from a solid, a liquid, and an aëriform body. How is the effect of heat upon the animal frame rendered more intense? Does a similar remark apply to cold?—122. What is the comparative weight of atmospheric air at the equator and at the poles? Upon what principle does this difference depend? Can you explain the phenomena of *winds*, with reference to the diffusion of heat by conveyance?—123. What is meant by radiation of heat? With what velocity does radiant heat move? In what ratio is its effect diminished? How is the power of radiation in different bodies determined? Upon what circumstance does the rapidity of radiation depend? Explain Leslie's experiments with the thermometer, and the tin canister. What is the radiating power of tarnished lead, compared with that of clean lead; of lamp-black, as compared with polished iron?—124. Upon what circumstance does the deposition of dew depend? In what condition of the atmosphere is dew most abundantly deposited? How is radiation of heat from the earth arrested? Show how the quantity of dew deposited on different substances, is proportional to the radiating power of their surfaces. What is hoar frost? How is it that trees escape the effects of severe frost, while herbage is destroyed by it?

125. In what three ways may the rays of heat, falling on the surface of a solid or liquid body, be disposed of? How is the temperature of the body, on which they fall, affected in each?—126. What relation is there between the reflection of light, and the reflection of heat, from the same surfaces? What relation

has the reflection of heat to radiation? Explain the condition of these properties in metals. Give instances. What effects may be produced by reflection of heat from a pair of concave metallic mirrors? Explain the phenomenon of the apparent radiation of cold? 127. What relation has absorption of heat to radiation? What to reflection? Does the absorption of the sun's rays depend on the *colour* of the absorbing body?—128. How is heat affected towards bodies which neither absorb nor reflect it? Show how the transmission of heat through bodies is affected by their temperature. Does the transmission of heat through bodies depend on their transparency? What is meant by the terms *diathermanous* and *diaphanous?*

129. Explain the deceptive effects which heat produces on the senses. What class of bodies, when heated, produce the strongest sensations? Show that heat and cold, so far as our sensations are concerned, are merely relative terms.—130. How is the bulk of bodies affected by heat?—131. What class of bodies expand most by heat? Is there any relation between the expansibility and the fusibility of metals? What is the pyrometer? Give an instance of unequal expansion by heat.—132. Do liquids expand more than solids, by heat? What liquids are the most expansible? Give instances. How does water exhibit a remarkable *exception* to the laws of expansion and contraction? How is the expansion of metals by heat applied to useful purposes?—133. Why are aëriform bodies greatly expansible? What is the amount of expansibility of air as compared with that of water; of water, as compared with iron? Give examples of the expansibility of air? What is the rate of expansion of aëriform bodies for each degree of temperature of Fahrenheit's thermometer?

134. What is a thermometer? What are its two fixed points? Explain the difference between Fahrenheit's, the Centigrade, and Reaumur's thermometers, How may their different modes of graduation be converted?—135. Explain the principle of the air thermometer. Why is it rarely employed? What is the differential thermometer, and what is its use?—136. What is the construction, and object, of the register thermometer? How are high temperatures measured?—137. How may a change in density be proved to be a result of change in temperature? What is the direct result of the repulsive property of heat? Describe an interesting experiment in proof of the change of density by temperature.

138. How is the *form* of bodies affected by heat? What are the melting points of lead, of tin, of ice, of ether? Prove that,

during the conversion of a solid into a liquid, heat is absorbed from surrounding bodies. With what propriety can it be stated that *freezing is a warming process*, and *melting a cooling process?*—139. Does the heat, absorbed by a body during the process of melting, raise the temperature of that body? What term is applied to this heat? Describe the experiments of Dr Black. What quantity of heat becomes latent in the conversion of ice into water? What beneficial result ensues from this phenomenon? What is meant by caloric of fluidity?—140. When water freezes, what becomes of its latent heat? Give some proofs of the liberation of latent heat during the process of freezing.—141. Explain the operation of freezing mixtures. Upon what circumstance do the phenomena depend?

142. What are vapours, and how are they produced?—143. Give some instances of evaporation at common temperatures. Describe the cryophorus.—144. What are the circumstances which influence evaporation? How may it be shown that the atmosphere contains watery vapour in suspension?—145. What is the hygrometer? How is the quantity of moisture in the atmosphere indicated by this instrument? Explain the Fig. 49.

146. What is meant by ebullition? What is steam? What is the relation, in point of bulk, between water and steam? What becomes of the heat which enters into water, during its conversion into steam? What is the amount of this latent heat? Does the amount of latent heat vary with the temperature at which vaporisation takes place?—147. When steam is reconverted into water, what becomes of its latent heat? How may its liberation be applied to useful purposes?

148. Is the boiling point of liquids affected by atmospheric pressure? What is the amount of this pressure? What is the ratio between elevation from the earth's surface and the temperature at which liquids boil? How is the atmospheric pressure indicated? What relation exists between the inches of mercury in the barometer, and the boiling point of water?—149. When the pressure of the atmosphere is removed, to what extent is the boiling point of liquids reduced? At what temperature will water boil in a good vacuum? Illustrate the effect of pressure on the boiling of water by experiment.—150. What other circumstances influence the boiling point of liquids?—151. Explain the phenomenon, by which water boils away *less* rapidly in a metallic cup heated to a high temperature, than it would in the cup at a lower temperature.—152. What is the temperature of steam, when formed in open vessels? What is meant by *high pressure steam*? Why is the application of high pressure steam

to the surface of the human body unattended by painful sensation? What is the elastic force of steam at 212°, when the barometer stands at 30 inches? What is the ratio between the elasticity of steam and increase of temperature?—153. Explain Fig. 50. How is the elastic force of steam estimated by means of this instrument?—154. What is meant by condensation of steam? What circumstances are required to produce effective and rapid condensation? Explain the operation of water as a condensing agent. How is this operation connected with the phenomenon of latent heat?—155. Show that the condensation of steam is attended by the production of a vacuum. Illustrate this fact by a simple experiment.—156. Explain Fig. 51. What is the moving power in this machine during the ascent of the piston? What is the moving power during its descent?—157. What is the amount of mechanical force produced by the evaporation of a cubic inch of water? Explain this with reference to Fig. 52. What would be the results of adding a weight of fifteen pounds to the piston?—158. State some economical applications of heat.—159. What is incandescence? What temperature is required to produce incandescence in solid and liquid bodies in the dark, and also in day-light? Under what circumstances do gases become incandescent? What appearances do bodies exhibit, as they pass from the lowest to the highest degree of incandescence?

160. Show that all bodies do not contain the same quantity of heat at the same temperature. What is this property of bodies termed? What is meant by specific heat? What is the specific heat of water, of sulphur, of iron, of silver, and of platinum? What body has the greatest capacity for heat? Show that the specific heat of a body varies with its physical state.—161. What relation exists between the capacity of bodies for heat and their specific gravities. Give examples. What are the results of increase of bulk? Illustrate this fact, in the case of a liquid, and of an aeriform, body. How is it shown that bodies contain a large quantity of latent heat?

CHAP. III.

OF MECHANICS.

162. *General Remarks.*—MECHANICS is the science which treats of the equilibrium and motion of bodies. That part of the subject which relates to the conditions of equilibrium, is called *statics;* while that which investigates the motion which a body acquires, when the forces applied to it are not in equilibrium, is termed *dynamics.* When a solid body which is at rest, but is capable of being moved about a certain point of its mass, is acted on by two or more forces in opposite directions, it either remains at rest, or is set in motion. It remains at rest, when the momenta of the moving forces are equal, and this condition is called the equilibrium or *statical momentum of the forces.* It is set in motion, when the momenta of the forces in one direction exceed those in the other, and its motion is in the direction of the greater momentum. The practical object of this science is, to teach the best modes of overcoming resistance by means of mechanical powers, and to apply motion to useful purposes by means of machinery.*

163. A *machine* is any instrument by which power, motion, or velocity, is applied, or regulated. A machine may be very simple, or exceedingly complex: thus, a pin is a machine for fastening clothes, and a steam engine is a machine for drawing carriages or propelling boats. As machines are constructed for a vast variety of purposes, their forms, powers, and kinds of movement, must depend on their intended uses. Several considerations ought to precede the actual construction of a new or untried machine. In constructing a machine, for instance, for raising a ship, regard must be had to the *inertia* or *weight* to be moved—to the *force* to be applied—to the *strength* of the materials—and the *space* or situation in which the proposed machine is to work. For if the force applied, or the strength of the materials, be insufficient, the machine is obviously useless; and if the force and strength be ample, but the space be wanting, the same result must follow. If the machine be intended for twisting the fibres of flexible

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* The general laws of statics and dynamics are applicable to fluids; but, owing to the peculiar difficulty attending the consideration of this class of bodies, they are generally treated separately; that part of the mechanics of fluids which relates to equilibrium being called *hydrostatics*, while that which investigates their motion is termed *hydrodynamics*.

substances into threads, no difficulty may be found in respect to power, strength of materials, or space to work in, but if the *velocity*, *direction*, and kind of motion obtained, be not applicable to the work intended, the labour is still lost. The *law* upon which the whole doctrine of the equilibrium of solids rests, may be thus stated:—*To increase any motive power, a proportionably greater velocity must be imparted to it, or it must be made to describe so much the longer space; to give a greater velocity to any mass, which it is desired to set in motion, it will be necessary to increase the force acting on the mass.*

164. "*Definitions.*—In mechanics, as well as in other sciences, there are words which must be explained, either because they are common words used in a peculiar sense, or because they are terms of art, not in common use. All technical terms will be as much as possible avoided, but still there are a few, which it is necessary here to explain.

"*Force* is the means by which bodies are set in motion, kept in motion, and when moving, are brought to rest. The force of gunpowder sets the ball in motion, and keeps it moving, until the force of resisting air, and the force of gravity, bring it to rest.

"*Power* is the means by which the machine is moved, and the force gained. Thus we have horse power, water power, and the power of weights.

"*Weight* is the resistance, or the thing to be moved by the force of the power. Thus, the stone is the weight to be moved by the force of the lever, or bar.

"*Fulcrum*, or prop, is the point or part on which a thing is supported, and about which it has more or less motion. In raising a stone, the thing on which the lever rests, is the fulcrum."

165. Machines are generally employed, either, 1. by means of a small force to hold *in equilibrio*, or to set in motion, a great weight; or, 2. by means of a considerable force to impart a great velocity to a small body. In mechanics, there are six *simple* machines, commonly called the *mechanical powers*, viz. the lever, the pulley, the wheel and axle, the inclined plane, the wedge, and the screw. All the different *compound* machines, however mixed or complex their construction, consist only of various combinations of these few individual powers.

I. THE LEVER.

166. *First kind of lever.*—Any inflexible rod, or bar, which is used in raising a weight, or surmounting a resistance, by being placed on a fulcrum, or prop, becomes a lever. This machine is the most simple of all the mechanical powers, and is therefore in universal use. Fig. 53 represents a straight lever, or *handspike*, called also a *crow-bar*, which is commonly used in raising and moving stone and other heavy bodies. The block B is the *weight*, or resistance, A is the *lever*, and C, the *fulcrum*. The *power* is the hand, or weight of a man, applied at A, to depress that end of the lever, and thus to raise the weight. It will be observed, that by this arrangement, the application of a small power may be used to overcome a great resistance.

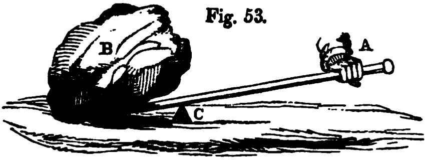
Fig. 53.

167. "The force to be obtained by the lever, depends on its length, together with the power applied, and the distance of the weight and power from the fulcrum. Suppose, Fig. 54, that A is the lever, B the fulcrum, D the weight to be raised, and C the power. Let D be considered three times as heavy as C, and the fulcrum three times as far from C as it is from D; then the weight and power will exactly balance each other. Thus, if the bar be four feet long, and the fulcrum three feet from the end, then three pounds on the long arm, will weigh just as much as nine pounds on the short arm, and these proportions will be found the same in all cases.

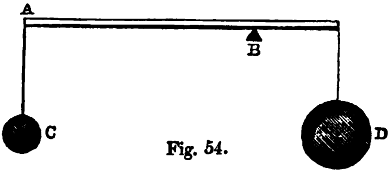
Fig. 54.

168. "When two weights balance each other, the fulcrum

is always the centre of gravity between them, and therefore, to make a small weight raise a large one, the fulcrum must be placed as near as possible to the large one, since the greater the distance *from the fulcrum the small weight* or power is placed, the greater will be its force. Suppose the weight B, Fig. 55, to be sixteen pounds, and suppose the fulcrum to be placed so near it, as to be raised by the power A, of four pounds, hanging equally distant from the fulcrum and the end of the lever. If now the power, A, be removed, and another of two pounds, C, be placed at the end of the lever, its force will be just equal to A, placed at the middle of the lever. But let the fulcrum be moved along to the middle of the lever, with the weight of sixteen pounds still suspended to it, it would then take another weight of sixteen pounds, instead of two pounds, to balance it, Fig. 56. Thus, the power which would balance 16 pounds, when the fulcrum is in one place, must be exchanged for another power weighing eight times as much, when the fulcrum is in another place.

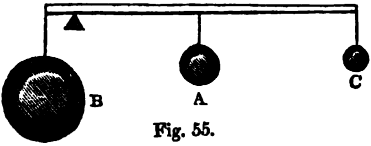

Fig. 55.

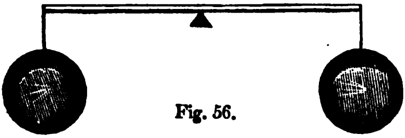

Fig. 56.

169. "From these investigations, we may draw the following general truth, or proposition, concerning the lever: '*That the force of the lever increases in proportion to the distance of the power from the fulcrum, and diminishes in proportion as the distance of the weight from the fulcrum increases.*' From this proposition may be drawn the following rule, by which the exact proportions between the weight or resistance, and the power, may be found. *Multiply the weight by its distance from the fulcrum; then multiply the power by its distance from the same point, and if the products*

are equal, the weight and the power will balance each other. Suppose a weight of 100 pounds on the short arm of a lever, 8 inches from the fulcrum, then another weight, or power, of 8 pounds, would be equal to this, at the distance of 100 inches from the fulcrum; because 8 multiplied by 100 is equal to 800; and 100 multiplied by 8 is equal to 800, and thus they would mutually counteract each other. Many instruments in common use are on the principle of this kind of lever.

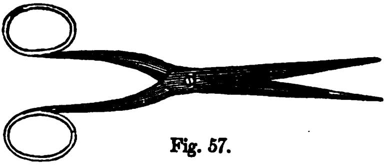

Fig. 57.

Scissors, Fig. 57, consist of two levers, the rivet being the fulcrum for both. The fingers are the power, and the cloth to be cut, the resistance to be overcome. *Pincers, forceps,* and *sugar cutters,* are examples of this kind of lever.

170. " A common scale-beam, used for weighing, is a lever, suspended at the centre of gravity, so that the two arms balance each other. Hence the machine is called a *balance.* The fulcrum, or what is called the *pivot,* is sharpened, like a wedge, and made of hardened steel, so as much as possible to avoid friction. A dish is suspended by cords to each end or arm of the lever, for the purpose of holding the articles to be weighed. When the whole is suspended at the point A, fig. 58, the beam or lever ought to remain in a horizontal position, one of its ends being exactly as high as the other. If the weights in the two dishes are equal, and the support exactly in the centre, they will always hang as repre-

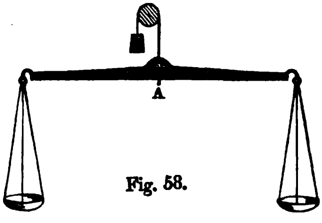

Fig. 58.

sented in the figure. A very slight variation of the point of support towards one end of the lever, will make a difference in the weights employed to balance each other. In weighing a pound of sugar, with a scale beam of eight inches long, if the point of support is half an inch too near the weight, the buyer would be cheated nearly one ounce, and consequently nearly one pound in every sixteen pounds. This fraud might instantly be detected by changing the places of the sugar and weight, for then the difference would be quite material, since the sugar would then seem to want twice as much additional weight as it did really want.

171. "The *steel-yard* differs from the balance, in having its support near one end, instead of in the middle, and also in having the weights suspended by hooks, instead of being placed in a dish. If we suppose the beam to be 7 inches long, and the hook, C, Fig. 59, to be one inch from the end, then the pound weight, A, will require an additional pound at B, for every inch that it is moved from it. This, however, supposes that the bar will balance itself, before any weights are attached to it.

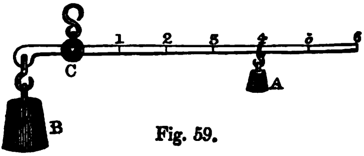

Fig. 59.

172. "In the kind of lever described, the weight to be raised is on one side of the fulcrum, and the power on the other. Thus *the fulcrum is between the power and the weight.*

173. *Second kind of lever.*—"There is another kind of lever, in the use of which, the weight is placed between the fulcrum and the power. In other words, the weight to be lifted, and the power by which it is moved, are on the same

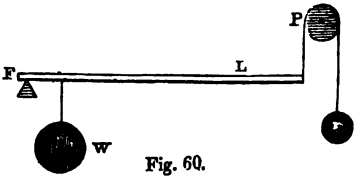

Fig. 60.

side of the prop. This arrangement is represented by Fig. 60, where W is the weight, L the lever, F the fulcrum, and P a pulley, over which a string is thrown, and a small weight suspended, as the power. In the common use of a lever of the first kind, the force is gained by bearing down the long arm of the lever, which is called *prying*. In the second kind, the force is gained by carrying the long arm in a contrary direction, or upward, and this is called *lifting*. Levers of the second kind are not so common as the first, but are frequently used for certain purposes. The oars of a boat are examples of the second kind. [The chipping-knife used by druggists, in which the end is fixed to a board, the common nutcrackers, and the chaff-cutter, are also instances of this kind of lever.] The water against which the blade of the oar pushes, is the fulcrum, the boat is the weight to be moved, and the hands of the man the power. Two men carrying a load between them on a pole, is also an example of this kind of lever. Each man acts as the power in moving the weight, and at the same time each becomes the fulcrum in respect to the other. If the weight happens to slide on the pole, the man towards whom it goes, has to bear more of it in proportion as its distance from him is less than before. A load at

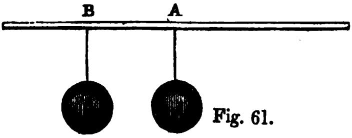

Fig. 61.

A, Fig. 61, is borne equally by the two men, being equally distant from each other; but at B, three quarters of its weight would be on the man at that end, because three quarters of the length of the lever would be on the side of the other man.

174. *Third kind of lever.*—" In the third, and last kind of lever, the weight is placed at one end, the fulcrum at the other end, and the power between them, or the hand is between the fulcrum and the weight to be lifted. This is represented by Fig. 62, where C is the fulcrum, A the power, suspended over the pulley B, and D is the weight to be raised. This kind of lever works to great disadvantage, since the power must be greater than the weight. It is therefore seldom used, except in cases where velocity and not force is required. In raising a ladder

from the ground to the roof of a house, men are obliged sometimes to make use of this principle, and the great difficulty of doing it, illustrates the mechanical disadvantage of this kind of lever." But as the purpose to be fulfilled is not always to increase the power of the agent, this kind of lever may be very usefully employed in machinery, where the employment of every species of motion is required. Thus, in turning, in weaving, in spinning, and in various kinds of manufacture, where great velocity, and not great force is required, and where the hands of the workman are occupied with the more important parts of the work, this kind of lever is employed with obvious advantage, the feet being engaged to give motion to the machinery.

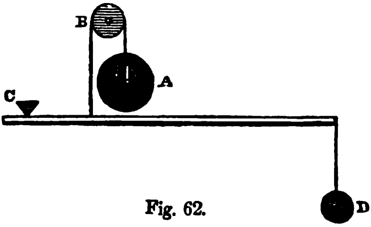

Fig. 62.

175. "We have now described three kinds of lever, and to make the difference between them still more obvious, and to avoid all confusion, we will here compare them together. In the first kind, the weight, or resistance, is on the short arm of the lever, the power, or hand, on the long arm, and the fulcrum between them. In the second kind, the weight is between the fulcrum and the hand, or power; and, in the third kind the hand is between the fulcrum and the weight. In Fig. 63, the weight and hand both act downwards. In 64, the weight and hand act in contrary directions, the hand upwards and the weight downwards, the weight being be-

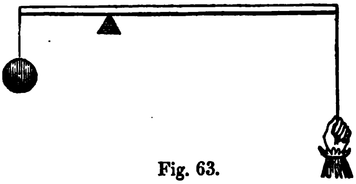

Fig. 63.

tween them. In 65, the hand and weight also act in con-

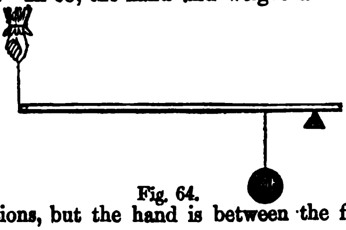

Fig. 64.

trary directions, but the hand is between the fulcrum and the weight.

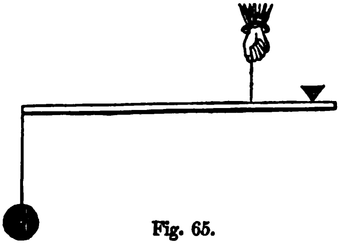

Fig. 65.

176. "*Compound lever.*—When several simple levers are connected together, and act one upon the other, the machine is called a *compound lever*. In this machine, as each lever acts as an individual, and with a force equal to the action of the next lever upon it, the force is increased or diminished, and becomes greater or less, in proportion to the number or kind of levers employed. We will illustrate this kind of lever by a single example, but must refer the inquisitive student to more extended works for a full investigation of the subject.

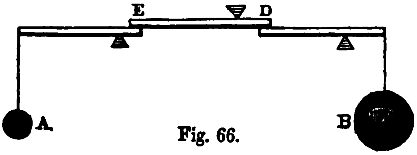

Fig. 66.

Fig. 66 represents a compound lever, consisting of three simple levers of the first kind. In calculating the force of this lever, the rule applies, which has already been given for the simple lever, namely, the length of the long arm is to be multiplied by the moving power, and that of the short one, by the weight, or resistance. Let us suppose, then, that the three levers in the figure are of the same length, the long arms being six inches, and the short ones, two inches long; required, the weight which a moving power of 1 pound at A will balance at B. In the first place, 1 pound at A, would balance 3 pounds at E, for the *lever* being 6 inches, and the power 1 pound, 6×1=6, and the short one being 2 inches, 2×3=6. The long arm of the second lever being also 6 inches, and moved with a power of 3 pounds, multiply the 3 by 6=18; and multiply the length of the short arm, being 2 inches, by 9=18. These two products being equal, the power upon the long arm of the third lever, at D, would be 9 pounds. 9 pounds×6=54, and 27×2, is 54; so that one pound at A would balance 27 at B. The increase of force is thus slow, because the proportion between the long and short arms, is only as 2 to 6, or in the proportions of 1, 3, 9.

177. "Now suppose the long arms of these levers to be 18 inches, and the short ones 1 inch, and the result will be surprisingly different, for then 1 pound at A would balance 18 pounds at E, and the second lever would have a power of 18 pounds. This being multiplied by the length of the lever, 18×18=324 pounds at D. The third lever would thus be moved by a power of 324 pounds, which, multiplied by 18 inches for the weight it would raise, would give 5832 pounds.

178. "The compound lever is employed in the construction of *weighing machines*, and particularly in cases where great weights are to be determined, in situations where other machines would be inconvenient, on account of their occupying too much space."

II.—WHEEL AND AXLE.

179. The mechanical power next to the lever in simplicity, is the *wheel and axle.*[*] It is, however, much more complex than the lever. It consists of a cylinder B, Fig. 67, which revolves about its axis, having a wheel A of larger diameter fixed to it. The weight C is suspended by a cord, which is

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[*] The term *axle* is employed in accordance with the name of the mechanical power, but it is not a correct term. The word axis, or axle, denotes in mechanics, the straight line, real or imaginary, about which a body turns. The machine is, therefore, more properly described as consisting of a cylinder, which revolves upon its axis, having a wheel of larger diameter fixed to it.

wound round the cylinder. The power, exerted by turning the crooked arm, or winch, at one extremity of the cylinder, acts on the periphery of the wheel. When the machine is in action, the wheel will take up, or throw off as much more rope than the cylinder, as its circumference is greater. If the circumference of the wheel is four times that of the cylinder, it will take up, or throw off, rope four times as fast. And since the circumference of the wheel is four times as great as that of the cylinder, 1 pound suspended at D will balance 4 pounds suspended at C. Consequently the power and the weight are in equilibrium, when the former is to the latter as the radius of the cylinder is to that of the wheel. This will be made evident by the following considerations. When the power has turned the wheel round once, the cylinder has also undergone one revolution. The power has then traversed a space indicated by the circumference of the wheel, whilst the weight has been raised a height equal to the perimeter of the cylinder. Hence it appears that the velocity of the power is to that of the weight as the circumference of the wheel is to that of the cylinder, *i. e.*, as their radii.

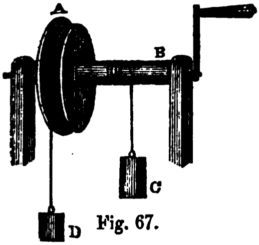


Fig. 67.

180. The principle of this machine is that of the lever. The definition and illustrations already given of the lever, exhibit this machine in its character of a simple bar, which is moveable in some part upon a prop or fulcrum. In the "wheel and axle," it will be seen how a lever acts when it is moveable on or about a fixed axis. When a lever is moveable upon an axis, and is capable of being turned completely round, it assumes the character of the diameter of a wheel. This will be made evident by consideration of Fig. 68. "This figure represents the machine endwise, so as to shew in what manner the lever operates. The two weights hanging in opposition to each other, the one on the wheel at A, and the

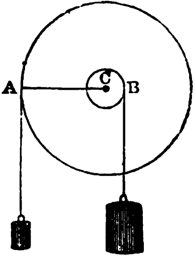


Fig. 68.

other on the cylinder at B, act in the same manner as if connected by the horizontal lever A B, passing from one to the other, having the common centre C as a fulcrum between them. The 'wheel and axle' therefore acts like a constant succession of levers, the long arm being half the diameter of the wheel, and the short one half the diameter of the cylinder; the common centre of both being the fulcrum. The 'wheel and axle' has therefore been called the *perpetual* lever.

181. "The great advantage of this mechanical arrangement is, that while a lever of the same power can raise a weight but a few inches at a time, and then only in a certain direction, this machine exerts a continual force, and in any direction wanted. To change the direction, it is only necessary that the rope by which the weight is to be raised should be carried in a line perpendicular to the axis of the machine, to the place below which the weight lies, and there be let fall over a pulley. Suppose the 'wheel and axle,' Fig. 69, is erected in the third storey of a store-house, with the cylinder over the scuttles, or doors through the floors, so that goods can be raised from the ground-floor in the direction of the weight A. Suppose also that the same store stands on a wharf, where ships come up to its side, and goods are to be removed from the vessels into the upper storeys. Instead of removing the goods into the store and hoisting them in the direction of A, it is only necessary to carry the rope B over the pulley C, which is at the end of a strong beam projecting out from the side of the store, and then the goods will be

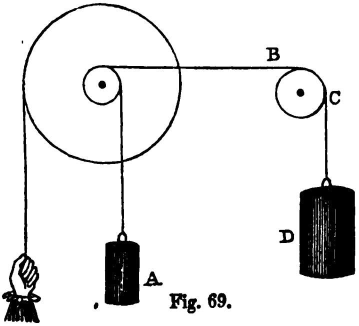


Fig. 69.

raised in the direction of D, thus saving the labour of moving them twice.

182. "The 'wheel and axle,' under different forms, is applied to various common purposes. The *capstan*, in universal use on board of ships and other vessels, is a cylinder placed upright, with a head or drum, A, Fig. 70, pierced with holes for the levers, B, C, D. The weight is drawn by the rope E, passing two or three times round the cylinder to prevent its slipping. This is a very powerful and useful machine. When not in use, the levers are taken out of their places and laid aside; and when great force is required, two or three men can push at each lever.

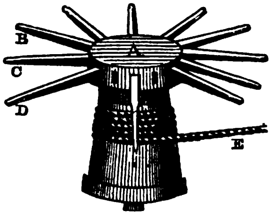


Fig. 70.

183. "The *common windlass* for drawing water is another modification of the 'wheel and axle.' The *winch*, or *crank*, by which it is turned, is moved round by the hand, and there is no difference in the principle whether a whole wheel is turned or a single spoke. The winch, therefore, answers to the wheel, while the rope is taken up, and the weight raised by the cylinder, as already described.

184. "In cases where great weights are to be raised, and it is required that the machine should be as small as possible, on account of room, the simple 'wheel and axle,' modified as represented by Fig. 71, is sometimes used. The cylinder may be considered in two parts, one of which is larger than

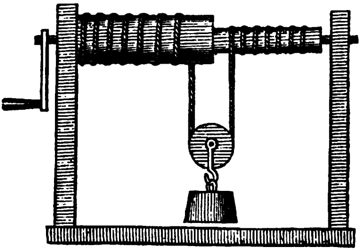


Fig. 71.

the other. The rope is attached by its two ends, to the ends of the cylinder. The weight to be raised is attached to a small pulley or wheel, round which the rope passes. The elevation of the weight may be thus described:—Upon turning the cylinder, the rope is coiled around the larger part, and at the same time it is thrown off the smaller. At every revolution, therefore, a portion of the rope will be drawn up equal to the circumference of the thicker part, and at the same time a portion equal to that of the thinner part will be let down. On the whole, then, one revolution of the machine will shorten the rope where the weight is suspended just as much as the difference between the circumference of the two parts.

185. "Now, to understand the principle on which this machine acts, we must refer to Fig. 72, where it is obvious that the two parts of the rope, A and B, equally support the weight D, and that the rope, as the machine turns, passes from the small part of the cylinder, E, to the large part H; therefore the weight does not rise in a perpendicular line towards C, the centre of both, but in a line between the outsides of the large and small parts. Let us consider what would be the result of changing the rope, A, to the larger part of the cylinder, so as to place the weight in a line perpendicular to the axis of motion. In this case, it is obvious that the machine would be in equilibrium, since the weight, D, would be divided between the two sides equally, and the two arms of a lever passing through the centre, C, would be of equal length, and therefore no advantage would be gained. But in the actual arrangement, the weight being sustained equally by the large and small parts, there is involved a lever power, the long arm of which is equal to half the diameter of the large part, while the short arm is equal to half the diameter of the small part, the fulcrum being between them."

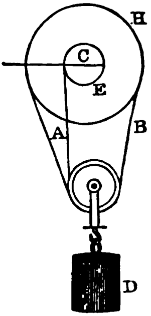


Fig. 72.

186. If the cord which supports the weight, or which transmits the action of the power to the weight, were wound round a conical surface, or a surface of variable diameter, instead of that of a cylinder, the ratio of the power to the weight would also vary considerably; and reciprocally, if the power, whose action is to be communicated through the

medium of such a machine as that under consideration, varies considerably, and is intended, notwithstanding, to produce the same effect, we arrive at the end proposed, by causing the action to be applied successively to radii which increase in length according as the power diminishes. An example of the adaptation of the machine to a varying power, occurs in watches and chronometers, and may be understood by a simple inspection of the machinery of a common watch. Here, the moving or maintaining power is a spring, fixed at one of its extremities to the axis or arbor of a barrel, and which, after several revolutions or coils, is attached to the interior of this barrel. A chain, with one of its extremities fixed to the convex surface of the barrel, is wound round a conical axis or fusee, to which the other extremity of the chain is attached. As the spring uncoils, the barrel turns round, and drawing the chain, causes the fusee also to turn round. But, since the force of the spring diminishes as it uncoils, a compensation is made for this reduction of the power, by giving a greater diameter to those parts of the fusee on which the last coils of the spring are exerted. By this contrivance, the machinery receives nearly equal impulses in equal times.

187. *System of wheels.*—" As the 'wheel and axle' is only a modification of the simple lever, so a system of wheels acting on each other, and transmitting the power to the resistance, is only another form of the compound lever. Such a combination is shewn at Fig. 73. The first wheel, A, by means of the teeth, or cogs around its axle, moves the second wheel,

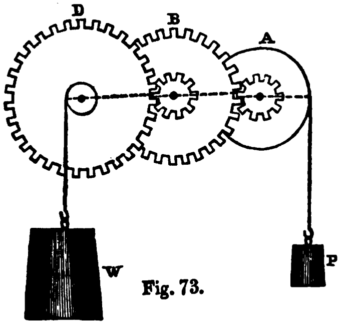


Fig. 73.

B, with a force equal to that of a lever, the long arm of which extends from the centre of the wheel and axle to the circumference of the wheel, where the power, P, is suspended, and the short arm from the same centre to the ends of the cogs. The dotted line, passing through the centre of the wheel A, shews the position of the lever, as the wheel now stands. The centre on which both wheels turn, it will be obvious, is the fulcrum of this lever. As the wheel turns, the short arm of this lever will act upon the long arm of the next lever by means of the teeth on the circumference of the wheel B, and this again through the teeth on the axle of B, will transmit its force to the circumference of the wheel D, and so by the short arm of the third lever to the weight W. As the power or small weight falls, therefore, the resistance, W, is raised with the multiplied force of three levers acting on each other.

188. "In respect to the force to be gained by such a machine, suppose the number of teeth on the axle of the wheel A to be six times less than the number of those on the circumference of the wheel B, then B would only turn round once, while A turned six times. And in like manner, if the number of teeth on the circumference of D be six times greater than those on the axle of B, then D would turn once, while B turned six times. Thus, six revolutions of A would make B revolve once, and six revolutions of B would make D revolve once. Therefore, A makes thirty-six revolutions, while D makes only one. The diameter of the wheel A being three times the diameter of the axle of the wheel D, and its velocity of motion being 36 to 1, 3 times 36 will give the weight which a power of 1 pound at P would raise at W. Thus, $36\times3=108$. One pound at P would therefore balance 108 pounds at W.

189. *No machine creates force.*—"If the student has attended closely to what has been said on mechanics, he will now be prepared to understand that no machine, however simple or complex it may be, can *create* the least degree of force. It is true that one man with a machine may apply a force which a hundred could not exert with their hands, but then it would take him a hundred times as long. Suppose there are twenty blocks of stone to be moved a hundred feet; perhaps twenty men, by taking each a block, would move them all in a minute. One man, with a capstan, we will suppose, may move them all at once; but this man, with his lever, would have to make one revolution for every foot he drew

the whole load towards him, and therefore to make one hundred revolutions to perform the whole work. It would also take him twenty times as long to do it as it took the twenty men. His task, indeed, would be more than twenty times harder than that performed by the twenty men, for, in addition to moving the stone, he would have the friction of the machinery to overcome, which commonly amounts to nearly one-third of the force employed. Hence there would be an actual loss of power by the use of the capstan, though it might be a convenience for the one man to do his work by its means, rather than to call in nineteen of his neighbours to assist him.

190. "The same principle holds good in respect to other machinery, where the strength of man is employed as the power, or prime mover. There is no advantage gained except that of convenience. In the use of the most simple of all machines, the lever, and where, at the same time, there is the least force lost by friction, there is no actual gain of power, for what seems to be gained in force, is always lost in velocity. Thus, if a lever is of such length as to raise 100 pounds an inch by the power of one pound, its long arm must pass through a space of 100 inches. Thus, what is gained in one way, is lost in another. Any power by which a machine is moved must be equal to the resistance to be overcome; and, in all cases where the power descends, there will be a proportion between the velocity with which it moves downwards and the velocity with which the weight moves upwards. There will be no difference in this respect whether the machine be simple or compound, for if its force be increased by increasing the number of levers, or wheels, the velocity of the moving power must also be increased as that of the resistance is diminished.

191. "There being, then, always a proportion between the velocity with which the moving force descends, and that with which the weight ascends, whatever this proportion may be, it is necessary that the power should have to the resistance the same ratio that the velocity of the resistance has to the velocity of the power. In other words, '*The power multiplied by the space through which it moves in a vertical direction, must be equal to the weight multiplied by the space through which it moves in a vertical direction.*' This law is known under the name of 'the law of virtual velocities,' and is considered the *golden rule* of mechanics.

192. "This principle has already been explained while treating of the lever; but that the student should want nothing to assist him in clearly comprehending so important a law, we will again illustrate it in a different manner. Suppose the weight of ten pounds to be suspended on the short arm of the lever, Fig. 74, and that the fulcrum is only one inch from the weight; then, if the lever be ten inches long on the other side of the fulcrum, one pound at A would raise or balance ten pounds at B. But in raising these ten pounds one inch in a vertical direction, the long arm of the lever must fall ten inches in a vertical direction, and therefore the velocity of A would be ten times the velocity of B. The application of this law or rule is apparent. The power is one pound, and the space through which it falls is ten inches, therefore 10×1=10. The weight is ten pounds, and the space through which it rises is one inch, therefore 1×10 =10. Thus, the power, multiplied by the space through which it moves, is exactly equal to the weight, multiplied by the space through which it moves.

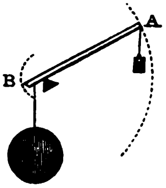


Fig. 74.

193. "Again, suppose the lever, Fig. 75, to be thirty inches long from the fulcrum to the point where the power P is suspended, and that the weight W is two inches from the fulcrum. If the power be 1 pound, the weight must be 15 pounds, to produce equilibrium, and the power P must fall thirty inches, to raise the weight W 2 inches. Therefore the power being one pound, and the space 30 inches, 30×1=30. The weight being 15 pounds, and the space 2 inches, 15×2=30. Thus, the power, multiplied by the space through which it falls, and the weight multiplied by the space through which it rises, are equal. However complex the machine may be, by which the force of a descending power is transmitted to

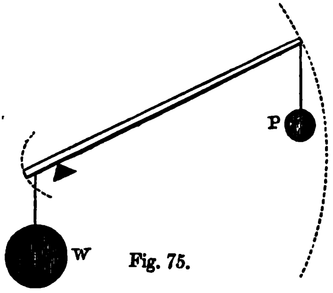


Fig. 75.

the weight to be raised, the same rule will apply, as it does to the action of the simple lever.

III. THE PULLEY.

194. The pulley consists of a solid wheel, called a *sheave*, fixed in a frame-work or *block*, and turning on its axis; a groove is formed round its circumference, over which a cord may pass. The several parts, taken together, are sometimes called the block, sometimes simply the pulley. Pulleys are of two kinds, the *fixed*, and the *moveable*. The fixed pulley, Fig. 76, revolves about its axis without changing its place; in this kind of pulley, the power and the weight, or resistance to be overcome, are both applied in directions which are tangents to the circumference of the pulley. In the moveable pulley, the weight or resistance is applied at the centre, or in a direction passing through the centre or axis of the pulley. One of the most obvious advantages of the pulley is, its enabling men to exert their own power in places where they cannot go themselves. Thus by means of a rope and wheel, a man can stand on the deck of a ship, and hoist a weight to the top-mast.

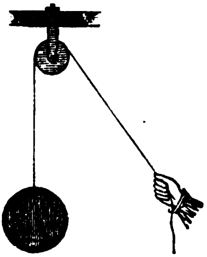


Fig. 76.

195. "By means of two fixed pulleys, a weight may be raised upward, while the power moves in a horizontal direction. The weight will also rise vertically through the same space that the rope is drawn horizontally. Fig. 77 represents two fixed pulleys, as they are arranged for such a purpose. In the erection of a lofty edifice, suppose the upper pulley to be suspended to some part of the building; then a horse, pulling at the rope A, would raise the weight, W, vertically, as far as he went horizontally.

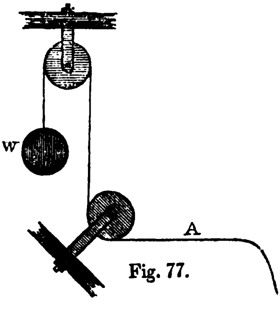


Fig. 77.

196. "In the use of the *wheel* of the pulley, there is no mechanical advantage, except that which arises from removing the friction, and diminishing the imperfect flexibility of the rope. In the mechanical effects of this machine, the result would be the same, were it to slide on a smooth surface with the same ease as that with which its motion makes the wheel revolve.

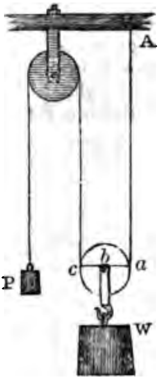


Fig. 78.

197. "In the use of the single *fixed* pulley, there can be no mechanical advantage, since the weight rises as fast as the power descends. This is obvious by Fig. 78; where it is also apparent that the power and weight must be exactly equal, to balance each other. In the single *moveable* pulley, Fig. 78, the same rope passes from the fixed point, A, to the power, P. It is evident, here, that the weight is supported equally by the two parts of the string between which it hangs. Therefore, if we call the weight, W, ten pounds, five pounds will be supported by one string, and five by the other. The power, then, will support twice its own weight, so that a person pulling with a force of five pounds at P, will raise ten pounds at W. The mechanical force, therefore, in respect to the power, is as two to one." It will be observed, by reference to the figure, that the *moveable* pulley, besides its motion round its axis, has also a progressive motion. The weight, W, hangs from the axis of the pulley, whilst the string which passes round it is secured at one end, and is acted upon at the other by the power P. Whether the string run parallel on each side of the pulley, or the power act vertically upward, in either case the pulley acts on the principle of a lever of the third kind. (§ 174), whose arms are to each other, as 1 to 2. To illustrate this identity of action, let *c a* be the axis of the pulley: then, *c* is the fulcrum, *b* the point of the lever on which the weight acts, and *a* that on which the power acts; therefore the distance, *c b*, of the weight from the fulcrum is equal to the radius, or 1, and the distance, *c a*, of the power is equal to the diameter, or 2. The statical momentum, therefore, requires a force which shall be equal to half the weight, or,

in other words, the *moveable pulley effects a saving equal to half the power.*

198. "In the foregoing example, it is supposed there are only two ropes, each of which bears an equal part of the weight. If the number of ropes be increased, the weight may be increased with the same power; or the power may be diminished in proportion as the number of ropes is increased. In Fig. 79, the number of ropes sustaining the weight is four, and therefore, the weight may be four times as great as the power. This principle must be evident, since it is plain that each rope sustains an equal part of the weight. The weight may therefore be considered as divided into four parts, and each part sustained by one rope.'

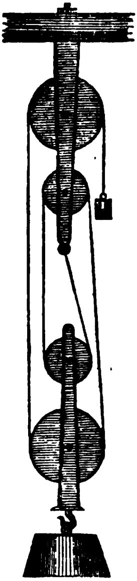


Fig. 79.

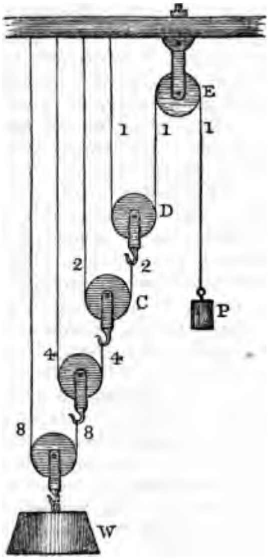


Fig. 80.

199. A *system of pulleys* is a number of pulleys, either all moveable, or both moveable and fixed acting in concert. A system of pulleys acts on the same principle as the com-

pound lever (§ 176). But the mechanical efficacy of a system of pulleys is derived entirely from the division of the weight among the strings employed in suspending it. "In Fig. 80, a system of pulleys is represented, in which the weight is sixteen times the power. The tension of the rope, D, E, is evidently equal to the power, P, because it sustains it; D being a moveable pulley, must sustain a weight equal to twice the power; but the weight which it sustains is the tension of the second rope, D, C. Hence the tension of the second rope is twice that of the first, and, in like manner, the tension of the third rope is twice that of the second, and so on, the weight being equal to twice the tension of the last rope.

200. "Suppose the weight W, to be sixteen pounds, then the two ropes, 8 and 8, would sustain just 8 pounds each, this being the whole weight divided equally between them. The next two ropes, 4 and 4, would evidently sustain but half this whole weight, because the other half is already sustained by a rope, fixed at its upper end. The next two ropes sustain but half of 4, for the same reason; and the next pair, 1 and 1, for the same reason, will sustain only half of 2. Lastly, the power, P, will balance two pounds, because it sustains but half this weight, the other half being sustained by the same rope, fixed at its upper end. It is evident that in this system each rope and pulley which is added will double the effect of the whole. Thus, by adding another rope and pulley beyond eight, the weight W might be 32 pounds, instead of 16, and still be balanced by the same power.

201. "In our calculations of the effects of pulleys, we have allowed nothing for the weight of the pulleys themselves, or for the friction of the ropes. In practice, however, it will be found, that nearly one-third must be allowed for friction, and that the power, therefore, to actually raise the weight, must be about one-third greater than has been allowed.

202. "The pulley, like other machines, obeys the laws of virtual velocities, already applied to the lever and wheel. *Thus*, "*in a system of pulleys, the ascent of the weight, or resistance, is as much less than the descent of the power, as the weight is greater than the power.*" If, as in the last example, the weight is 16 pounds, and the power one pound, the weight will rise only one foot, while the power descends 16 feet.

203. "In the single fixed pulley, the weight and power are equal, and consequently, the weight rises as fast as the

power descends. With such a pulley a man may raise himself up to the mast-head by his own weight. Suppose a rope is thrown over a pulley, and a man ties one end of it round his body, and takes the other end in his hands, he has the power of throwing more of his weight on that side than on the other; and, when he does this, his body will rise. Thus, although the power and the weight are the same individual, still the man can change his centre of gravity, so as to make the power greater than the weight, or the weight greater than the power, and thus can elevate one half his weight in succession.

IV.—THE INCLINED PLANE.

204. "The fourth simple mechanical power is the *inclined plane.* This power consists of a plain smooth surface, which is inclined towards or from the earth. It is represented by Fig. 81, where from A to B is the *inclined plane;* the line from D to A is its *height*, and that from B to D its *base.* A board, with one end on the ground, and the other end resting on a block, becomes an inclined plane. This machine, being both useful and easily constructed, is in very general use, especially where heavy bodies are to be raised only to a small height. Thus, a man, by means of an inclined plane, which he can readily construct with a board, or couple of bars, can raise a load into his wagon which ten men could not lift with their hands.

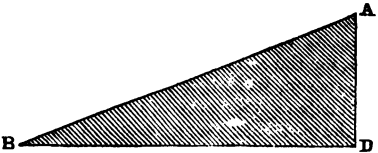


Fig. 81.

205. "The power required to force a given weight up an inclined plane is in a certain proportion to its height, and the length of its base, or, in other words, the force must be in proportion to the rapidity of its inclination. The power P, Fig. 82, pulling a weight up the inclined plane from C to D, only raises it in a perpendicular direction from E to D, by acting along the whole length of the plane. If the plane be twice as long as it is high, that is, if the line from C to D be

double the length of that from E to D, then one pound at P will balance two pounds anywhere between D and C. It is

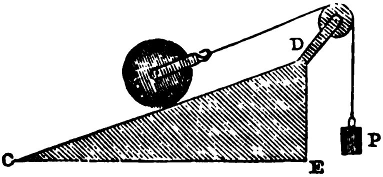


Fig. 82.

evident, by a glance at this Fig., that were the base, that is, the line from E to C, lengthened, the height from E to D being the same, a less power at P would balance an equal weight any where on the inclined plane; and so, on the contrary, were the base made shorter, that is, the plane more steep, the power must be increased in proportion.

206. "Suppose two inclined planes, Fig. 83, of the same height, with bases of different lengths; then the weight and

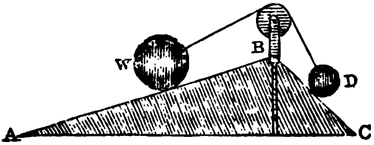


Fig. 83.

power will be to each other as the length of the planes. If the length from A to B is two feet, and that from B to C one foot, then two pounds at D will balance four pounds at W, and so in this proportion, whether the planes be longer or shorter.

207. "The same principle, with respect to the vertical velocities of the weight and power, applies to the inclined plane, in common with the other mechanical powers. Suppose the inclined plane, Fig. 84, to be two feet from A to B, and one foot from C to B, then, as we have already seen by Fig. 82, a power of one pound at P would balance a weight of two pounds at W. Now, in the fall of the power to draw up the weight, it is obvious that its vertical descent must be just twice the vertical ascent of the weight; for the power must fall down the distance from A to B to draw the weight that distance; but the vertical height to which the weight W

is raised, is only from C to B. Thus, the power, being two pounds, must fall two feet to raise the weight, four pounds, one foot; and thus the power and weight, multiplied by the several velocities, are equal.

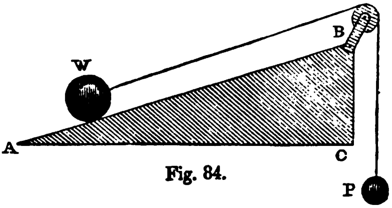


Fig. 84.

208. "When the power of an inclined plane is considered as a machine, it must therefore be estimated by the proportion which the length bears to the height; the power being increased in proportion as the elevation of the plane is diminished. Hilly roads may be regarded as inclined planes, and loads drawn upon them in carriages, considered in reference to the powers which impel them, and subject to all the conditions which we have stated, with respect to inclined planes. The power required to draw a load up a hill, is in proportion to the length and elevation of the inclined plane. On a road, perfectly horizontal, if the power is sufficient to overcome the friction, and the resistance of the atmosphere, the carriage will move. But if the road rise one foot in fifteen, besides these impediments, the moving power will have to lift one fifteenth part of the load. If two roads rise, one at the rate of a foot in fifteen feet, and another at the rate of a foot in twenty, then the same power that would move a given weight fifteen feet on the one, would move it twenty feet on the other, in the same time. In the building of roads, therefore, both speed and power are very often sacrificed to want of judgment, or ignorance of these laws. A road, as every traveller knows, is often continued directly over a hill, when half the power, with the increase of speed, on a level road around it, would gain the same distance in half the time.

V. THE WEDGE.

209. "The next simple mechanical power is the *wedge.* This instrument may be considered as two inclined planes, placed base to base. It is much employed for the purpose of

splitting or dividing solid bodies, such as wood and stone. Fig. 85, represents such a wedge as is usually employed in cleaving timber. This instrument is also used in raising ships, and preparing them to launch, and for a variety of other purposes. Nails, awls, needles, and many cutting instruments, act on the principle of this machine. There is much difficulty in estimating the power of the wedge, since this depends on the force or the number of blows given it, together with the obliquity of its sides. A wedge of great obliquity would require hard blows to drive it forward, for the same reason that a plane much inclined requires much force to roll a heavy body up it. But were the obliquity of the wedge, and the force of each blow given, still it would be difficult to ascertain the exact power of the wedge in ordinary cases, for, in the splitting of timber and stone, for instance, the divided parts act as levers, and thus greatly increase the power of the wedge. Thus in a log of wood six feet long, when split one half of its length, the other half is divided with ease, because the two parts act as levers, the lengths of which constantly increase as the cleft extends from the wedge."

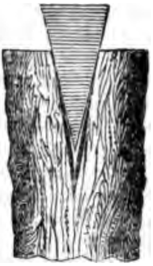


Fig. 85.

VI.—THE SCREW.

210. The *screw* is the sixth and last simple mechanical power. It may be considered as a modification of the inclined plane, or as a winding wedge. It is in fact, an inclined plane running spirally round a spindle; or it may be described, in other words, as formed by winding a right-angled triangle about a cylinder, so that the longer of the two sides containing the right angle shall be perpendicular to the cylinder, as will be seen in Fig. 86. Suppose A to be a piece of paper cut into the form of an inclined plane, or of a right-angled triangle, and rolled round the cylinder of wood D, the edge of the former figure, or the hypothenuse of the latter, would form the spiral line, called the *thread* or *worm* of the screw. Every part of this line which

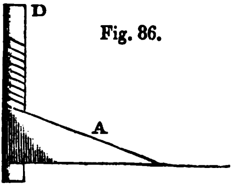


Fig. 86.

passes once round the periphery of the cylinder, is called a *spire* of the thread or worm, and each such part requires an equal portion of the inclined plane or triangle. The distance of one spire from the next coincides with the height of the corresponding portions of the plane or triangle, and is called the *breadth* of the screw. If the finger be placed between two spires of a screw, and the screw be turned round once, the finger will be raised upward to a distance equal to that of the two spires apart. In this manner, the finger is raised up the inclined plane as it runs round the cylinder.

211. When the screw line consists of one continuous elevation, as above described, the cylinder forms *a male screw.* But its power may be transmitted and employed by means of another screw, having a spiral grove running through it, which exactly fits the thread of the former; this is called the *nut* or *female screw.* The combination of these two parts constitutes the mechanical power known as the screw. If the nut is fixed, the (male) screw, on being turned round, advances forward; but if the (male) screw is fixed, the nut, when turned, advances along its thread. Fig. 87 represents the former kind of screw, being such as is commonly used in pressing paper, and other substances. The nut N, through which the screw passes, answers also for one of the beams of the press. If the screw be turned to the right, it will advance downwards, while the nut stands still.

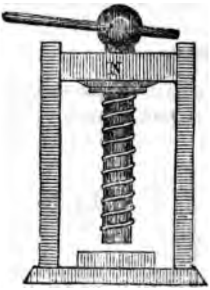


Fig. 87.

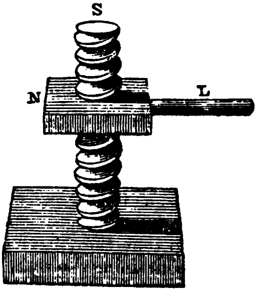


Fig. 88.

212. A screw of the second kind is represented by Fig. 88. In this, the screw is fixed, while the nut, N, by being turned by the lever, L, from right to left, will advance down the screw. In practice, the screw is never used as a simple mechanical machine; the power being always applied by means of a

lever, passing through the head of the screw, as in Fig. 87, or into the nut, as in Fig. 88. The screw, therefore, acts with the combined power of the inclined plane and the lever, and its force is such as to be limited only by the strength of the materials of which it is made. In investigating the effects of this machine, we must, therefore, take into account both these simple mechanical powers, so that the screw now becomes really a compound engine.

213. "In the inclined plane, we have already seen, that the less it is inclined, the more easy is the ascent up it. In applying the same principle to the screw, it is obvious, that the greater the distance of the threads from each other, the more rapid the inclination, and, consequently, the greater must be the power to turn it, under a given weight. On the contrary, if the thread inclines downwards but slightly, it will turn with less power, for the same reason that a man can roll a heavy weight up a plane but little inclined. Therefore, the finer the screw, or the nearer the threads to each other, the greater will be the pressure under a given power. Let us suppose two screws, the one having the threads one inch apart, and the other half an inch apart; then the force which the first screw will give with the same power at the lever will be only half that given by the second. The second screw must be turned twice as many times round as the first, to go through the same space, but what is lost in velocity is gained in power. At the lever of the first, two men would raise a given weight to a given height by making one revolution; while at the lever of the second, one man would raise the same weight to the same height, by making two revolutions.

214. "It is apparent that the length of the inclined plane, up which a body moves in one revolution, is the circumference of the screw, and its height, the interval between the threads. The proportion of its power would therefore be "as the circumference of the screw to the distance between the threads, so is the weight to the power." By this rule the power of the screw alone can be found; but as this machine is moved by means of the lever, we must estimate its force by the combined power of both. In this case, the circumference described by the end of the lever employed, is taken, instead of the circumference of the screw itself. The means by which the force of the screw may be found, is therefore by multiplying the circumference which the lever describes

by the power. Thus, '*the power multiplied by the circumference which it describes, is equal to the weight or resistance, multiplied by the distance between the two contiguous threads.*' Hence the efficacy of the screw may be increased, by increasing the length of the lever by which it is turned, or by diminishing the distance between the threads. If, then, we know the length of the lever, the distance between the threads, and the weight to be raised, we can readily calculate the power; or, the power being given, and the distance of the threads and the length of the lever known, we can estimate the weight the screw will raise.

215. "Thus, suppose the length of the lever to be forty inches, the distance of the threads one inch, and the weight 8000 pounds; required, the power, at the end of the lever, to raise the weight. The lever being 40 inches, the diameter of the circle, which the end describes, is 80 inches. The circumference is a little more than three times the diameter, but we will call it just three times. Then, 80×3=240 inches, the circumference of the circle. The distance of the threads is 1 inch, and the weight 8000 pounds. To find the power, multiply the weight by the distance of the threads, and divide by the circumference of the circle. Thus,

circum.		in.		weight.		power.
240	×	1	: :	8000	=	33⅓

The power at the end of the lever must therefore be 33⅓ pounds. In practice this power would require to be increased about one-third, on account of friction.

216. "*Perpetual screw.*—The force of the screw is sometimes employed to turn a wheel, by acting on its teeth. In this case it is called the *perpetual screw*. Fig. 89 represents such a machine. It is apparent, that by turning the crank C, the wheel will revolve, for the thread of the screw passes between the cogs of the wheel. By means of an axle, through the centre of this wheel, like the common wheel and axle, this becomes an exceedingly powerful machine, but like all other contrivances for obtaining great power, its effective mo-

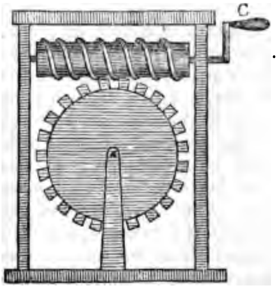


Fig. 89.

tion is exceedingly slow. It has, however, some disadvantages, and particularly the great friction between the thread of the screw and the teeth of the wheel, which prevents it from being generally employed to raise weights.

217. "*All the mechanical powers resolved into three.*—We have now enumerated and described all the mechanical powers usually denominated simple. They are six in number, namely, the Lever, Wheel and Axle, Pulley, Wedge, Inclined Plane, and Screw. In respect to the principle on which they act, they may be resolved into three simple powers, namely, the lever, the inclined plane, and the pulley; for it has been shown that the wheel and axle is only another form of the lever, and that the screw is but a modification of the inclined plane." The principles developed by the mechanical powers are reduced by Peschel to a still greater simplicity. It will be found, he says, that all the laws which regulate equilibrium in each, either depend immediately on those which are established with regard to the lever, or may be deduced from the principal laws of motive powers. The *lever* may, therefore, be regarded as the *fundamental machine;* and as all compound machines are merely constructions of the simple ones, it follows that *the lever furnishes the fundamental law for the entire theory of machinery.*

218. "The variety of motions we witness in the little engine which makes cards, by being supplied with wire for the teeth, and strips of leather to stick them through, would itself seem to involve more mechanical powers than those enumerated. This engine takes the wire from a reel, bends it into the form of teeth; cuts it off; makes two holes in the leather for the tooth to pass through; sticks it through; then gives it another bend, on the opposite side of the leather; graduates the spaces between the rows of teeth, and between one tooth and another; and, at the same time, carries the leather backwards and forwards, before the point where the teeth are introduced, with a motion so exactly corresponding with the motions of the parts which make and stick the teeth, as not to produce the difference of a hair's-breadth in the distance between them. All this is done without the aid of human hands, any farther than to put the leather in its place, and turn a crank; or, in some instances, many of these machines are turned at once, by means of three or four dogs, walking on an inclined plane which revolves. Such a machine displays the wonderful ingenuity and perseverance of man, and

at first sight would seem to set at nought the idea that the lever and wheel were the chief simple powers concerned in its motions. But when these motions are examined singly and deliberately, we are soon convinced that the wheel, variously modified, is the principal mechanical power in the whole engine.

219. " *Use of machinery.*—It has already been stated, that notwithstanding the amount of time and ingenuity which men have spent on the construction of machinery, and in attempting to multiply their powers, there has, as yet, been none produced, in which the power was not obtained at the expense of velocity, or velocity at the expense of power; and, therefore, no actual force is ever generated by machinery. Suppose a man able to raise a weight by means of a compound pulley of ten ropes, which it would take ten men to raise, by one rope without pulleys. If the weight is to be raised a yard, the ten men by pulling their rope a yard will do the work. But the man with the pulleys must draw his rope ten yards to raise the weight one yard, and in addition to this, he has to overcome the friction of the ten pulleys, making about one-third more actual labour than was employed by the ten men.

220. " But notwithstanding these inconveniences, the use of machinery is of vast importance to the world. 1. On board of a ship, a few men will raise an anchor with a capstan, which it would take ten or twenty times the same number to raise without it, and thus the expense of shipping men expressly for this purpose is saved. 2. One man with a lever, may move a stone which it would take twenty men to move without it, and though it should take him twenty times as long, he would still be the gainer, since it would be more convenient, and less expensive for him to do the work himself, than to employ twenty others to do it for him. 3. When men employ the natural elements as a power to overcome resistance by means of machinery, there is a vast saving of animal labour. Thus mills, and all kinds of engines, which are kept in motion by the power of water, or wind, or steam, save animal labour equal to the power it takes to keep them in motion.

QUESTIONS ON CHAP. III.

162. Of what does the science of Mechanics treat? What is meant by statics? What is meant by dynamics? When a body is acted upon by two or more forces, under what circumstances does it remain at rest? Under what circumstances is it set in motion? How is its motive direction determined? What is the object of the science of mechanics? What is meant by the terms hydrostatics and hydrodynamics?—163. What is a machine? Mention one of the most simple, and one of the most complex of machines. What circumstances must be considered in the construction of a machine? State the law upon which the whole doctrine of the equilibrium of solids rests.—164. What is meant by force in mechanics? What is meant by power? What is understood by weight? What is the fulcrum?—165. For what two purposes are machines generally employed? Enumerate the simple mechanical powers.

166. What is a lever? What is the simplest of all mechanical powers? Explain Fig. 53. Which is the weight? Where is the fulcrum? Where is the power applied? What is the power in this case?—167. On what does the force to be obtained by the lever depend? Suppose a lever four feet long, and the fulcrum one foot from the end, what number of pounds will balance each other at the ends?—168. When weights balance each other, at what point between them must the fulcrum be? Suppose a weight of 16 pounds on the short arm of a lever is counterbalanced by 4 pounds in the middle of the long arm, what power would balance this weight at the end of the lever? Suppose the fulcrum to be moved to the middle of the lever, what power would then be equal to 16 pounds?—169. What is the general proposition drawn from these results? What is the rule for finding the proportions between the weight and power? Give an illustration of this rule. What instruments operate on the principle of this lever? When the scissors are used, what is the resistance, and what the power?—170. In the common scale-beam where is the fulcrum? In what position ought the scale-beam to hang? How may a fraudulent scale-beam be made? How may the cheat be detected?—171. How does the steelyard differ from the balance?—172. In the first kind of lever, where is the fulcrum, in respect to the weight and power?—173. In the second kind, where is the fulcrum, in respect to the weight and power? What is the action of the first kind called? What is the action of the second kind called? Give examples of the second kind

of lever. In rowing a boat, what is the fulcrum, what the weight, and what the power? What other illustrations of this principle are given?—174. In the third kind of lever, where are the respective places of the weight, power and fulcrum? What is the disadvantage of this kind of lever? Give an example of the use of the third kind of lever.—175. In what direction do the hand and weight act in the first kind of lever? In what direction do they act in the second kind? In what direction do they act in the third kind?—176. What is a compound lever? By what rule is the force of the compound lever calculated? How many pounds weight will be raised by three levers connected, of eight inches each, with the fulcrum two inches from the end, by a power of one pound?—177. If the long arms of the levers be 18 inches, and the short one one inch, how much will a power of one pound balance?—178. In what machines is the compound lever employed? What advantages do these machines possess over others?

179. What is the next simple mechanical power to the lever? Describe this machine. Explain Fig. 67. When are the power and the weight in this machine in equilibrium?—180. On what principle does this machine act? In Fig. 68, which is the fulcrum, and which the two arms of the lever? What is this machine called, in reference to the principle on which it acts?—181. What is the great advantage of this machine over the lever and other mechanical powers? Describe Fig. 69, and point out the manner in which weights can be raised by letting fall a rope over the pulley.—182. What is the capstan? Where is it chiefly used? What are the peculiar advantages of this form of the wheel and axle?—183. In the common windlass, what part answers to the wheel?—184. Explain Fig. 71. Why is the rope shortened, and the weight raised?—185. What is the design of Fig. 72? Does the weight rise perpendicular to the axis of motion? Suppose the cylinder was, throughout, of the same size, what would be the consequence? On what principle does this machine act? Which are the long and the short arms of the lever, and where is the fulcrum?—186. Explain the machinery of the common watch, and show the compensation therein provided for the reduction of the power.—187. On what principle does a system of wheels act, as represented in Fig. 73. Explain Fig. 73, and show how the power P is transferred by the action of levers to W.—188. What weight will one pound at P balance at W?—189. Is there any actual power gained by the use of machinery? Suppose 20 men to move 20 stones to a certain distance with their hands, while one man moves them back to the

same place with a capstan, which performs the most actual labour? Why? Why, then, is machinery a convenience?—190. How is this illustrated? It is said, that the velocity of the power downwards, must be in proportion to that of the weight upwards—Does it make any difference in this respect, whether the machine be simple or compound?—191. What is the golden rule of mechanics? Under what name is this law known?—192. Explain Fig. 74, and show how the rule is illustrated by that figure.—193. Explain Fig. 75, and show how the same rule is illustrated by it. What is said of the application of this rule to complex machines?

194. Of what parts is a pulley composed? What is the character of the fixed pulley? In what directions do the power and the weight act in the fixed pulley? In what direction does the weight act in the moveable pulley? State one of the most obvious advantages of the pulley?—195. How must two fixed pulleys be placed, to raise a weight vertically, as far as the power goes horizontally?—196. What is the advantage of the wheel of the pulley?—197. Is there any mechanical advantage in the fixed pulley? What weight at P, Fig. 78, will balance ten pounds at W? Show how the moveable pulley acts like a lever of the third kind.—198. Suppose the number of ropes be increased, and the weight increased, must the power be increased also? Suppose the weight, Fig. 79, to be 32 pounds, what will each rope bear?—199. What is meant by a system of pulleys? What does the mechanical efficacy of a system of pulleys depend on?—200. Explain Fig. 80, and show what part of the weight each rope sustains, and why 1 pound at P will balance 16 pounds at W. Explain the reason why each additional rope and pulley will double the effect of the whole.—201. In compound machines, how much of the power must be allowed for the friction?—202. State the law of virtual velocities, as applied to the pulley.—203. How may a man raise himself up by means of a rope and single fixed pulley?

204. What is an inclined plane? On what occasions is this power chiefly used? Suppose a man wants to load a barrel of cider into his wagon, how does he make an inclined plane for this purpose?—205. To roll a given weight up an inclined plane, to what must the force be proportioned? Explain Fig. 82.—206. If the length of the long plane, Fig. 83, be double that of the short one, what must be the proportion between the power and the weight?—207. What is said of the application of the law of vertical velocities to the inclined plane? Explain Fig. 84, and show why the power must fall twice as far as the weight rises.—

208. How must the power of an inclined plane be estimated? Illustrate this with reference to hilly roads.

209. On what principle does the wedge act? In what case is this power useful? What common instruments act on the principle of the wedge? What difficulty is there in estimating the power of the wedge?

210. On what principle does the screw act? How is it shown that the screw is a modification of the inclined plane, and of a right-angled triangle? Explain Fig. 86. What is meant by the thread, the spire, and the breadth of the screw?—211. What is meant by a male, and what by a female screw? By what other name is the latter designated? Explain Fig. 87. Which is the screw, and which the nut? Which way must the screw be turned to make it advance through the nut?—212. How does the screw, Fig. 88 differ from Fig. 87? Is the screw ever used as a simple machine? By what other simple power is it moved? What two simple mechanical powers are concerned in the force of the screw?—213. Why does the nearness of the threads make a difference in the force of the screw? Suppose one screw, with its threads one inch apart, and another half an inch apart, what will be their difference in force?—214. What is the length of the inclined plane up which a body moves by one revolution of the screw? What would be the height to which the same body would move at one revolution? How is the force of the screw estimated? How may the efficacy of the screw be increased? The length of the lever, the distance between the threads, and the weight being known, how can the power be found?—215. Give an example.—216. What is the screw called, when it is employed to turn a wheel? What is the object of this machine for raising weights?—217. How may all the mechanical powers be resolved into three simple powers?—218. What is said of the card-making machine? What are the chief mechanical powers concerned in its motion?—219. Is any actual force generated by machinery? Can great velocity and great force be produced by the same machinery? Why not? Which performs the greater labour, ten men who lift a weight with their hands, or one man who does the same with ten pulleys? Why?—220. Enumerate some important uses of machinery.

CHAP. IV.

OF HYDROSTATICS.

221. HYDROSTATICS is that branch of mechanics which treats of the weight, pressure, and equilibrium of fluids, when in a state of rest; and of these properties of solids, when immersed in fluids. A *fluid* is a collection of material particles, which are easily moved among themselves. The fluids which nature presents to us, approach more or less to this condition. The adhesion which exists among the particles of several fluids, as tar, honey, and some metals in a state of fusion, and which gives rise to what is called *viscidity*, opposes itself to the separation of the particles. But, in treating of hydrostatics, no account is taken of this adhesion; the subject matter relates only to the perfect fluids.

222. "One of the most obvious properties of fluids is the facility with which they yield to the impressions of other bodies, and the rapidity with which they recover their former state when the pressure is removed. The cause of this is apparently the freedom with which the particles of liquids slide over, or among each other; their cohesive attraction being so slight as to be overcome by the least impression. On this want of cohesion among their particles seem to depend the peculiar mechanical properties of these bodies. In solids, there is such a connexion between the particles, that if one part moves, the other part must move also. But in fluids, one portion of the mass may be in motion, while the other is at rest. In solids, the pressure is always downwards, or towards the centre of the earth's gravity; but in fluids, the particles seem to act on each other in every direction, and hence, when confined, the pressure is sideways, and even upwards, as well as downwards."

223. Fluids are commonly distinguished into the elastic, and the inelastic. 1. *Elastic* fluids are those which are capable of being compressed into a smaller bulk, and of recovering their dimensions when the compressing force is removed. Of this kind are atmospheric air and all the gases. Some *gases* may be compressed to such an extent, as to assume the form of liquids and solids: that is, from the condition of being invisible, they may be rendered perceptible to the eye, and appreciable by the touch, as in the case of

carbonic acid gas. *Vapours* differ from air and the gases, by losing the form of elastic fluids and returning to the state of liquids, when compressed to a certain degree, or when their temperature is sufficiently reduced. This remark must, however, be made with certain restrictions, several of the gases having been condensed into liquids by Mr Faraday, under pressures varying from two to fifty atmospheres, and at temperatures ranging from 45° to 60°. 2. *Inelastic* fluids are those formerly supposed to be incompressible, and, among these were ranged water, mercury, alcohol, and liquids generally. But the term is incorrect: the phenomenon of the transmission of sound through water and other liquids, had long ago indicated that they were capable of being compressed. Canton clearly detected this property, by observing the volume occupied respectively by oil, water, and mercury, first placed in a vacuum, and afterwards exposed to the pressure of the atmosphere. But the most decisive experiments on this subject have been made within the last few years by Mr Perkins, and are here detailed.

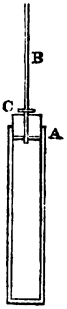


Fig. 90.

224. "The experiments were made by means of a hollow cylinder, Fig. 90, which was closed at the bottom, and made water-tight at the top by a cap screwed on. Through this cap at A, passed the rod B, which was five-sixteenths of an inch in diameter. The rod was so nicely fitted to the cap as also to be water-tight. Around the rod at C there was placed a flexible ring which could be easily pushed up or down, but fitted so closely as to remain on any part where it was placed. A cannon of sufficient size to receive this cylinder, which was three inches in diameter, was furnished with a strong cap and forcing pump, and set vertically into the ground. The cannon and cylinder were next filled with water, and the cylinder, with its rod drawn out, and the ring placed down to the cap, as in the figure, was plunged into the cannon. The water in the cannon was then subjected to an immense pressure by means of the forcing pump, after which, on examination of the apparatus, it was found that the ring, C, instead of being where it was placed, was eight inches up the rod. The water in the cylinder being compressed into a smaller space, by the pressure of that in the cannon, the rod was driven in while under pressure, but was forced out again by the expansion of the water, when

the pressure was removed. Thus, the ring on the rod would indicate the distance to which it had been forced in during the greatest pressure. This experiment proved that water, under the pressure of one thousand atmospheres, that is, the weight of 15,000 pounds to the square inch, was reduced in bulk about one part in twenty-four. So slight a degree of elasticity, under such immense pressure, is not appreciable under ordinary circumstances, and, therefore, in practice, as in common experiments on this fluid, water is considered as inelastic.

EQUAL PRESSURE OF WATER.

225. "The particles of water, and other fluids, when confined, press on the vessel which confines them, in all directions, both upwards, downwards, and sideways. From this property of fluids, together with their weight, or gravity, very unexpected and surprising effects are produced. The effect of this property, which we shall first examine, is, that a quantity of water, however small, will balance another quantity however large. Fig. 91 represents a common coffee-pot, supposed to be filled up to the dotted line A, with a decoction of coffee, or any other liquid. The coffee, we know, stands exactly at the same height, both in the body of the pot, and in its spout. Therefore, the small quantity in the spout, balances the large quantity in the pot, or presses with the same force downwards, as that in the body of the pot presses upwards. This is obviously true, otherwise, the large quantity would sink below the dotted line, while that in the spout would rise above it, and run over.

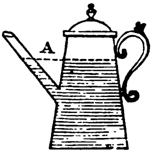


Fig. 91.

226. "The same principle is more strikingly illustrated by Fig. 92. Suppose the cistern A to be capable of holding one hundred gallons, and into its bottom there be fitted the tube B, bent, as seen in the figure, and capable of containing one gallon. The top of the cistern, and that of the tube, being open, pour water into the tube at C, and it will rise up through the perpendicular bend into the cistern, and if the process be continued, the cistern will be filled by pouring

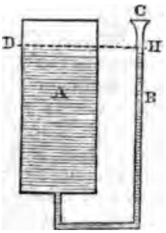


Fig. 92.

water into the tube. Now, it is plain, that the gallon of water in the tube, presses against the hundred gallons in the cistern, with a force equal to the pressure of the hundred gallons, otherwise, that in the tube would be forced upwards higher than that in the cistern, whereas, we find that the surfaces of both stand exactly at the same height.

227. "From these experiments we learn, '*that the pressure of a fluid is not in proportion to its quantity, but to its height, and that a large quantity of water in an open vessel, presses down with no more force, than a small quantity of the same height.*'

228. "In this respect, the size or shape of a vessel is of no consequence, for if a number of vessels, differing entirely from each other in figure, position, and capacity, have a communication made between them, and one be filled with water, the surface of the fluid, in all, will be at exactly the same elevation. If, therefore, the water stands at an equal height in all, the pressure in one must be just equal to that in another, and so equal to that in all the others. To make this obvious, suppose a number of vessels, of different shapes and sizes, as represented by Fig. 93, to have a communication between them, by means of a small tube, passing from the one to the other. If, now, one of these vessels be filled with water, or if water be poured into the tube A, all the other vessels will be filled at the same instant, up to the line B C. Therefore, the pressure of the water in A, balances that in 1, 2, 3, &c., while the pressure in each of these vessels, is equal to that in the others, and so an equilibrium is produced throughout the whole series. If an ounce of water be poured into the tube A, it will produce a pressure on the contents of all the other vessels, equal to the pressure of all the others on the tube; for, it will force the water in all the other vessels to rise upwards to an equal height with that in

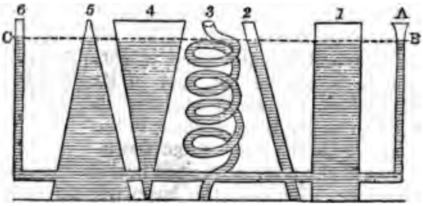


Fig. 93.

the tube itself. Hence, we must conclude, that the pressure in each vessel, is not only equal to that in any of the others, but also that the pressure in any one, is equal to that in all the others.

229. "From this we learn, that the shape or size of a vessel has no influence on the pressure of its liquid contents, but that the pressure of water is as its height, whether the quantity be great or small. We learn, also, that in no case will the weight of a quantity of liquid, however large, force another quantity, however small, above the level of its own surface. This is proved by experiment; for if, from a pond situated on a mountain, water be conveyed in an inch tube to the valley, a hundred feet below, the water will rise just a hundred feet in the tube; that is, exactly to the level of the surface of the pond. Thus the water in the pond, and that in the tube, press equally against each other, and produce an exact equilibrium.

230. "Thus far we have considered the fluid as acting only in vessels with open mouths, and therefore at liberty to seek its balance, or equilibrium, by its own gravity. Its pressure, we have seen, is in proportion to its height, and not to its bulk. Now, by other experiments, it is ascertained, *that the pressure of a liquid is in proportion to its height, and its area at the base.* Suppose a vessel, ten feet high, and two feet in diameter, such as is represented at A, Fig. 94, to be filled with water; there would be a certain amount of pressure, say at C, near the bottom. Let D represent another vessel, of the same diameter at the bottom, but only a foot high, and closed at the top. Now if a small tube, say the fourth of an inch in diameter, be inserted into the cover of the vessel D, and this tube be carried to the height of the vessel A, and then the vessel and tube be filled with water, the pressure on the bottoms and sides of both vessels to the same height will be equal, and jets of water starting from D and C, will have exactly the same force. This might at first seem improbable, but to convince ourselves of its truth, we have only to consider, that any impression made on one portion of the confined fluid in the

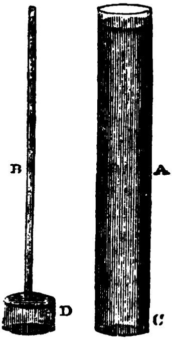


Fig. 94.

vessel D, is instantly communicated to the whole mass. Therefore, the water in the tube B presses with the same force on every other portion of the water in D, as it does on that small portion over which it stands.

231. "This principle is illustrated in a very striking manner, by the experiment, which has often been made, of bursting the strongest wine-cask with a few ounces of water Suppose A, Fig. 95, to be a strong cask, already filled with water, and suppose the tube B, thirty feet high, to be screwed, water tight, into its head. When water is poured into the tube, so as to fill it gradually, the cask will show increasing signs of pressure, by emitting the water through the pores of the wood, and between the joints; and, finally, as the tube is filled, the cask will burst asunder. 2. The same apparatus will serve to illustrate the upward pressure of water; for if a small stop-cock be fitted to the upper head, on turning this, when the tube is filled, a jet of water will spirt up with a force, and to a height, that will astonish all who never before saw such an experiment. 3. In theory, the water will spout to the same height with that which gives the pressure, but, in practice, it is found to fall short, in the following proportions: If the tube be twenty feet high, and the orifice for the jet half an inch in diameter, the water will spout nearly nineteen feet. If the tube be fifty feet high, the jet will rise upwards of forty feet; and if a hundred feet, it will rise above eighty feet. It is understood, in every case, that the tubes are to be kept full of water. The height of these jets show the astonishing effects that a small quantity of fluid produces when pressing from a perpendicular elevation.

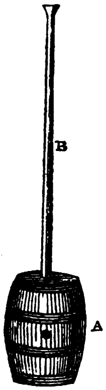


Fig. 95.

232. "*Hydrostatic bellows.*—An instrument called the hydrostatic bellows, also shows, in a striking manner, the great force of a small quantity of water, pressing in a perpendicular direction. 1. This instrument consists of two boards, connected together with strong leather, in the manner of the common bellows. It is then furnished with a tube A, Fig. 96, which communicates between the two boards. A person standing on the upper board, may raise himself up by pouring water into the tube. If the tube holds an ounce

of water, and has an area equal to a thousandth part of the area of the top of the bellows, one ounce of water in the tube will balance a thousand ounces placed on the bellows." 2. Suppose, instead of the bellows, a short wide metallic vessel to be filled with water, and covered over with a bladder, on which a thin plate of wood is placed for the purpose of receiving weights, the force of a small quantity of water may be thus estimated. As a cubic inch of water weighs about half an ounce, it follows that every inch of water in the tube, above the level of that in the metallic vessel, will exert a pressure of one pound upon 32 square inches of the surface of water in the metallic vessel. Suppose the surface of the water in this vessel to be 32 square inches, and the tube to contain a column of water of 100 inches, then this column will exert a pressure of 100 pounds, which is equal to the weight of a column of water standing over the vessel, having a diameter equal to that of the vessel, and reaching as high as the level of the water in the tube. This apparatus is called the *anatomical syphon*.

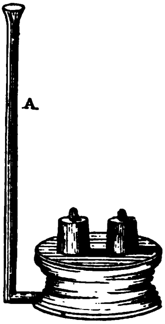


Fig. 96.

233. "*Hydraulic press.*—This property of water was applied by Mr Bramah to the construction of his *hydraulic* press. But instead of a high tube of water, which in most cases could not be so readily obtained, he substituted a strong forcing pump, and instead of the leather bellows, a metallic pump barrel and piston. 1. This arrangement will be understood by Fig. 97, where the pump barrel, A, B, is represented as divided lengthwise, in order to show the inside. The piston, C, is fitted so accurately to the barrel, as to work up and down water tight; both barrel and piston being made of iron. The thing to be broken, or pressed, is laid on the flat surface, I, there being above this, a strong frame to meet the pressure, not shown in the

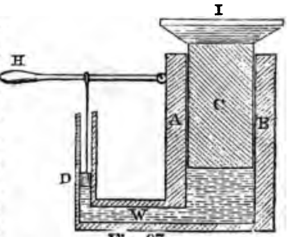


Fig. 97.

figure. The small forcing pump, of which D is the piston, and H the lever by which it is worked, is also made of iron. 2. Now, suppose the space between the small piston and the large one, at W, to be filled with water, then, on forcing down the small piston, D, there will be a pressure against the large piston, C, the whole force of which will be in proportion as the aperture in which C works, is greater than that in which D works. If the piston, D, is half an inch in diameter, and the piston, C, one foot in diameter, then the pressure on C will be 576 times greater than that on D. Therefore, if we suppose the pressure of the small piston to be one ton, the large piston will be forced up against any resistance, with a pressure equal to the weight of 576 tons. It would be easy for a single man to give the pressure of a ton at D, by means of the lever, and, therefore, a man, with this engine, would be able to exert a force equal to the weight of near 600 tons. 3. It is evident, that the force to be obtained by this principle, can only be limited by the strength of the materials of which the engine is made. Thus, if a pressure of two tons be given to a piston, the diameter of which is only a quarter of an inch, the force transmitted to the other piston, if three feet in diameter, would be upwards of 40,000 tons; but such a force is much too great for the strength of any material with which we are acquainted. 4. A small quantity of water, extending to a great elevation, would give the pressure above described, it being only for the sake of convenience, that the forcing pump is employed, instead of a column of water.

234. "There is no doubt, but in the operations of nature, great effects are sometimes produced among mountains, by

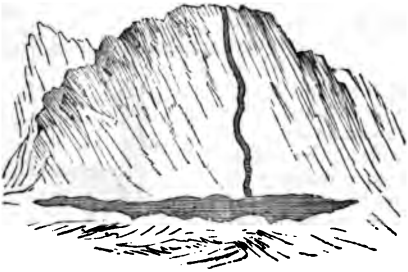


Fig. 98.

a small quantity of water finding its way to a reservoir in the crevices of the rocks far beneath. Suppose in the interior of a mountain, Fig. 98, there should be a space of ten yards square, and an inch deep, filled with water, and closed up on all sides; and suppose, that in the course of time, a small fissure, no more than an inch in diameter, should be opened by the water, from the height of two hundred feet above, down to this little reservoir. The consequence might be, that the side of the mountain would burst asunder, for the pressure, under the circumstances supposed, would be equal to the weight of five thousand tons.

235. "*Pressure on vessels with oblique sides.*—It is obvious that in a vessel, the sides of which are every where perpendicular to each other, the pressure on the bottom will be as the height, and that the pressure on the sides will every where be equal at an equal depth of the liquid. But it is not so obvious, in a vessel having oblique sides, that is, diverging outwards from the bottom, or converging from the bottom towards the top, in what manner the force of pressure will be sustained. Now, the pressure on the bottom of any vessel, no matter what the shape may be, is equal to the height of the fluid, and the area of the bottom. Hence the pressure on the bottom of the vessel sloping outwards, Fig. 99, will be just equal to what it would be, were the sides perpendicular, and the same would be the case did the sides slop inwards instead of outwards. In a vessel of this shape, the sides sustain a pressure equal to the perpendicular height of the fluid above any given point. Thus, if the point 1 sustain a pressure of one pound, 2, being twice as far below the surface, will have a pressure equal to two pounds, and so in this proportion with respect to the other eight parts marked on the side of the vessel.

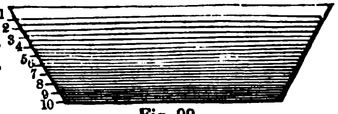


Fig. 99.

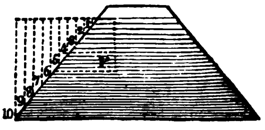


Fig. 100.

236. "On the contrary, did the sides of the vessel slope inwards instead of outwards, as represented by Fig. 100, still the same consequences would ensue, that is, the perpendicu-

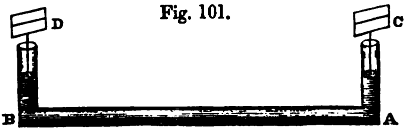
lar height, in both cases, would make the pressure equal. For although, in the latter case, the perpendicular height is not above the point pressed upon, still the same effect is produced by the pressure of the fluid in the direction perpendicular to the plane of the side, and since fluids press equally in all directions, this pressure is just the same as though it were perpendicularly above the point pressed upon, as in the direction of the dotted lines. To show that this is the case, we will suppose that P, Fig. 100, is a particle of the liquid at the same depth below the surface as the division marked 5 on the side of the vessel; this particle is evidently pressed downwards by the incumbent weight of the column of fluid P, A. But since fluids press equally in all directions, this particle must be pressed upwards and sideways with the same force that it is pressed downwards, and, therefore, must be pressed from P towards the side of the vessel, marked 5, with the same force that it would be if the pressure was perpendicular above that part of the vessel.

237. "From all that has been stated, we learn, that if the sides of the vessels, 99 and 100, be equally inclined, though in contrary directions to their bottoms, and the vessels be filled with equal depths of water, the sides being of equal dimensions, will be pressed equally, though the actual quantity of fluid in each be quite different from each other.

WATER LEVEL.

238. "We have seen that in whatever situation water is placed, it always tends to seek a *level*. Thus, if several vessels, communicating with each other, be filled with water, the fluid will be at the same height in all, and the level will be indicated by a straight line drawn through all the vessels, as in Fig. 101. It is on the principle of this tendency that the little instrument called the *water level* is constructed.

Fig. 101.



The form of this instrument is represented by Fig. 101. It consists of a tube, A, B, with its two ends turned at right angles, and left open. Into one of the ends is poured water or mercury until the fluid rises a little in the angles of the tube. On the surface of the fluid at each end are then placed small floats, carrying upright frames, across which are drawn small wires or hairs, as seen at C and D. These hairs are called the *sights*, and are across the line of the tube. It is obvious that this instrument will always indicate a level when the floats are at the same height in respect to each other, and not in respect to their comparative heights in the ends of the tube, for if one end of the instrument be held lower than the other, still the floats must always be at the same height. To use this level, therefore, we have only to bring the two *sights*, so that one will range with the other; and on placing the eye at C, and looking towards D, this is determined in a moment. This level is indispensable in the construction of canals and aqueducts, since the engineer depends entirely on it to ascertain whether the water can be carried over a given hill or mountain.

239. "The common *spirit level* consists of a glass tube, Fig. 102, filled with spirit of wine, excepting a small space in which there is left a bubble of air. This bubble, when the instrument is laid on a level surface, will be exactly in the middle of the tube, and therefore to adjust a level, it is only necessary to bring the bubble to this position. The glass tube is inclosed in a brass case, which is cut out on the upper side, so that the bubble may be seen, as represented in the figure. This instrument is employed by builders to level their work, and is highly convenient for that purpose, since it is only necessary to lay it on a beam to try its level.

Fig. 102.

240. *Improved water level.*—"Let A, Fig. 103, be a straight glass tube, having two legs, or two other glass tubes, rising from each end at right angles. Let the tube A, and a part of the legs, be filled with mer-

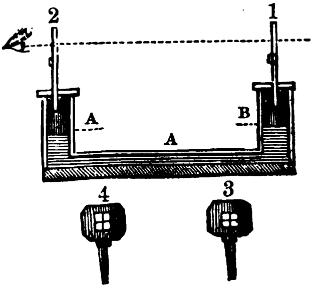


Fig. 103.

cury, or some other liquid, and on the surfaces, *a*, *b*, of the liquid, let floats be placed carrying upright wires, to the ends of which are attached sights at 1, 2. These sights are represented by 3, 4, and consist of two fine threads, or hairs, stretched at right angles across a square, and are placed at right angles to the length of the instrument. They are so adjusted that the points where the hairs intersect each other, shall be at equal heights above the floats. This adjustment may be made in the following manner:

"Let the eye be placed behind one of the sights, looking through it at the other, so as to make the points, where the hairs intersect, cover each other, and let some distant object, covered by this point be observed. Then let the instrument be reversed, and let the points of intersection of the hairs be viewed in the same way, so as to cover each other. If they are observed to cover the same distant object as before, they will be of equal heights above the surfaces of the liquid. But, if the same distant points be not observed in the direction of these points, then one or the other of the sights must be raised or lowered, by an adjustment provided for that purpose, until the points of intersection be brought to correspond. These points will then be properly adjusted, and the line passing through them, will be exactly horizontal. All points seen in the direction of the sights will be on the level of the instrument.

"The principles on which this adjustment depends are easily explained: if the intersections of the hairs be at the same distance from the floats, the line joining those intersections will evidently be parallel to the lines joining the surfaces *a*, *b*, of the liquid, and will therefore be level. But if one of these points be more distant from the floats than the other, the line joining the intersections will point upwards if viewed from the lower sight, and downwards, if viewed from the higher one. The accuracy of the results of this instrument, will be greatly increased by lengthening the tube A.

SPECIFIC GRAVITY.

241. "If a tumbler be filled with water to the brim, and an egg, or any other heavy solid, be dropped into it, a quantity of the fluid, exactly equal to the size of the egg, or other solid, will be displaced, and will flow over the side of the vessel. Bodies which sink in water, therefore, displace a quantity of the fluid equal to their own bulks. Now, it is

found, by experiment, that when any solid substance sinks in water, it loses, while in the fluid, a portion of its weight, just equal to the weight of the bulk of water which it displaces. This is readily made evident by experiment. Take a piece of ivory, or any other substance that will sink in water, and weigh it accurately in the usual manner; then suspend it by a thread, or hair, in the empty cup A, Fig. 104, and then balance it, as shown in the figure. Now pour water into the cup, and it will be found that the suspended body will lose a part of its weight, so that a certain number of grains must be taken from the opposite scale, in order to make the scales balance as before the water was poured in. The number of grains taken from the opposite scale is just the weight of a quantity of water equal to the bulk of the body so suspended.

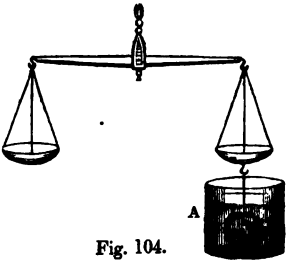


Fig. 104.

242. "It is on the principle that bodies weigh less in the water than they do when weighed out of it, or in the air, that water becomes the means of ascertaining their specific gravities, for it is by comparing the weight of a body in the water, with what it weighs out of it, that its specific gravity is determined. Thus, suppose a cubic inch of gold weighs nineteen ounces, and on being weighed in water, weighs only eighteen ounces, or loses a nineteenth part of its weight, it will prove that gold, bulk for bulk, is nineteen times heavier than water, and thus nineteen would be the specific gravity of gold. And so if a cube of copper weigh nine ounces in the air, and only eight ounces in the water, then copper, bulk for bulk, is nine times as heavy as water, and therefore has a specific gravity of nine. If the body weigh less, bulk for bulk, than water, it is obvious that it will not sink in it, and therefore weights must be added to the lighter body to ascertain how much less it weighs than water. The specific gravity of a body, then, is merely its weight, compared with the same bulk of water; and water is thus made the standard by which the weights of all other bodies are compared.

243. "To take the specific gravity of a *solid* which sinks in water, first weigh the body in the usual manner, and note

down the number of grains it weighs, then with a hair or fine thread suspend it from the bottom of the scale-dish in a vessel of water, as represented by Fig. 104. As it weighs less in water, weights must be added to the side of the scale where the body is suspended until they exactly balance each other. Next note down the number of grains so added, and they will shew the difference between the weight of the body in air and in water. It is obvious that the greater the specific gravity of the body, the less, comparatively, will be this difference, because each body displaces only its own bulk of water, and some bodies of the same bulk will weigh many times as much as others. For example, we will suppose that a piece of platina, weighing twenty-two ounces, will displace an ounce of water, while a piece of silver weighing twenty-two ounces, will displace two ounces of water. The platina, therefore, when suspended as above described, will require one ounce to make the scales balance, while the same weight of silver will require two ounces for the same purpose. The platina, therefore, bulk for bulk, will weigh twice as much as the silver, and will have twice as much specific gravity.

244. "Having noted down the difference between the weight of the body in air and in water, as above explained, the specific gravity is found by dividing the weight in air, by the loss in water. The greater the loss, therefore, the less will be the specific gravity, the bulk being the same. Thus, in the above example, 22 ounces of platina was supposed to lose one ounce in water, while 22 ounces of silver lost two ounces in water. Now, 22 divided by 1, the loss of the platina is 22; and 22 divided by 2, the loss in the silver is 11. So that the specific gravity of platina is 22, while that of silver is 11. The specific gravities of these metals are, however, a little less than here estimated."

245. The specific gravity of a *liquid* body is ascertained by filling a small bottle of known weight with it, and with water successively, and weighing them. The specific gravity of a *gaseous* body is ascertained by comparing it with atmospheric air. The first step is to find the weight of a given volume of air. For this purpose a flask, provided with a stopcock, is weighed when full of air; the air is then withdrawn by means of the air-pump, and the flask is again weighed; the difference between the two weights is that of the volume of air. By similar means the weight of any gas may be found, and its specific gravity, with reference to atmospheric air, determined.

246. The influence of *gravity* resembles that of cohesion in masses, in preventing that intimate mixture which favours chemical action. Hence, when two bodies differ in specific gravity, their combination is opposed. Oil floats on water, and refuses to combine with it, being specifically lighter. Salt sinks in water, being heavier; and it is only by agitating the solution, that the salt can be equally diffused throughout it. In melting together metals of different specific gravities, it is necessary to stir the mixture, to prevent the heavier metal from subsiding to the bottom.

HYDROMETER.

247. "The *Hydrometer* is an instrument by which the specific gravities of fluids are ascertained, by the depth to which it sinks below their surfaces. Suppose a cubic inch of lead loses, when weighed in water, 253 grains, and when weighed in alcohol, only 209 grains, then, according to the principle already recited, a cubic inch of water actually weighs 253, and a cubic inch of alcohol 209 grains, for when a body is weighed in fluid, it loses just the weight of the fluid it displaces. Water, as we have already seen, (§ 241,) is the standard by which the weights of other bodies are compared, and by ascertaining what a given bulk of any substance weighs in water, and then what it weighs in any other fluid, the comparative weight of water and this fluid will be known. For if, as in the above example, a certain bulk of water weighs 253 grains, and the same bulk of alcohol only 209 grains, then alcohol has a specific gravity nearly one-fourth less than water.

248. "It is on this principle that the hydrometer is constructed. It is composed of a hollow ball of glass, or metal, with a graduated scale rising from its upper part, and a weight on its under part, which serves to balance it in the fluid. Such an instrument is represented by Fig. 105, of which B is the graduated scale, and A the weight, the hollow ball being between them. To prepare this instrument for use, weights, in grains, or half grains, are put into the little ball A, until the scale is carried down, so that a certain mark on it coincides exactly with the surface of the water. This mark, then, becomes the standard of comparison between water and any other liquid, in which the

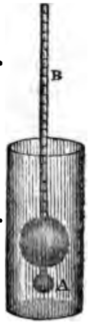


Fig. 105.

hydrometer is placed. If plunged into a fluid lighter than water, it will sink, and consequently the fluid will rise higher on the scale. If the fluid is heavier than water, the scale will rise above the surface in proportion, and thus it is ascertained, in a moment, whether any fluid has a greater or less specific gravity than water. To know precisely how much the fluid varies from the standard, the scale is marked off into degrees, which indicate grains by weight, so that it is ascertained, very exactly, how much the specific gravity of one fluid differs from that of another.

249. "Water being the standard by which the weights of other substances are compared, it is placed as the unit, or point of comparison, and is therefore 1, 10, 100, or 1000, the ciphers being added whenever there are fractional parts expressing the specific gravity of the body. It is always understood, therefore, that the specific gravity of water is 1, and when it is said a body has a specific gravity of 2, it is only meant, that such a body is, bulk for bulk, twice as heavy as water. If the substance is lighter than water, it has a specific gravity of 0, with a fractional part. Thus alcohol has a specific gravity of 0.809, that is, 809, water being 1000.

250 "By means of this instrument, it can be told with great accuracy, how much water has been added to spirits, for the greater the quantity of water, the higher will the scale rise above the surface. The adulteration of milk with water, can also be readily detected with it, for as new milk has a specific gravity of 1032, water being 1000, a very small quantity of water mixed with it would be indicated by the instrument.

THE SYPHON.

251 "Take a tube, bent like the letter U, and having filled it with water, place a finger on each end, and in this state plunge one of the ends into a vessel of water, so that the end in the water shall be a little the higher, then remove the fingers, and the liquid will flow out, and continue to do so, until the vessel is exhausted. A tube acting in this manner, is called a *syphon*, and is represented by Fig. 106. The reason why the water flows from the end of the tube A, and, consequently, ascends through the

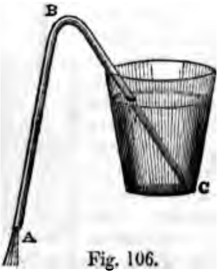


Fig. 106.

other part, is, that there is a greater weight of the fluid from B to A, than from C to B, because the perpendicular height from B to A is the greatest. The weight of the water from B to A falling downwards, by its gravity, tends to form a vacuum, or void space, in that leg of the tube, but the pressure of the atmosphere on the water in the vessel, constantly forces the fluid up the other leg of the tube, to fill the void space, and thus the stream is continued as long as any water remains in the vessel."

252. From this account it is evident that the uninterrupted flow is owing to the unequal pressure of the columns of liquid in the two legs of the syphon. In both legs the upward pressure of the atmosphere is equally exerted: in the immersed leg, the pressure is transmitted by the liquid in the vessel; in the other leg, it acts immediately at the aperture. This pressure of the air is, in both cases, opposed by the weight of the liquid, and as the columns of liquid are of unequal length, the greater force of gravity of the larger column determines the pressure, that is, the flow of the liquid in this direction. The influence of the atmosphere in producing this phenomenon, may be ascertained by inserting a syphon air-tight unto one of the openings of a double-mouthed bottle: so long as the other mouth remains open, the liquid will continue to flow; but, if this mouth be closed with a cork, the liquid will cease to escape. If the experiment be made under the receiver of an air-pump, the flow will cease when the air has been rarefied to a certain extent.

253. "*Intermitting springs.*—The action of the syphon depends upon the same principle as the action of the pump, namely, the pressure of the atmosphere, and therefore its explanation properly belongs to Pneumatics. It is introduced here merely for the purpose of illustrating the phenomena of intermitting springs; a subject which properly belongs to Pneumàtics. Some springs, situated on the sides of mountains, flow for a while with great violence, and then cease entirely. After a time, they begin to flow again, and then suddenly stop, as before. These are called *intermitting springs*, and they owe their peculiarities to nothing more than natural syphons, existing in the mountains from whence the water flows. Fig. 107 is the section of a mountain and spring, showing how the principle of the syphon operates to produce the effect described. Suppose there is a crevice, or hollow in the rock from A to B, and a narrow fissure leading from it, in the form

of the syphon, B C. The water, from the rills F E, filling the hollow, up to the line A D, it will then discharge itself through the syphon, and continue to run until the water is exhausted down to the leg of the syphon B, when it will cease. Then the water from the rills continuing to run until the hollow is again filled up to the same line, the syphon again begins to act, and again discharges the contents of the reservoir as before, and thus the spring P, at one moment, flows with great violence, and the next moment ceases entirely. The hollow, above the line A D, is supposed not to be filled with the water at all, since the syphon begins to act whenever the fluid rises up to the bend D. During the dry seasons of the year, it is obvious, that such a spring would cease to flow entirely, and would begin again only when the water from the mountain filled the cavity through the rills.

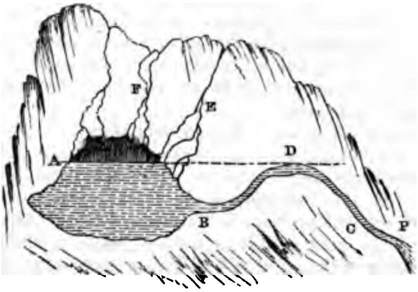


Fig. 107.

QUESTIONS ON CHAP. IV.

221. WHAT branch of mechanics is denoted by the term Hydrostatics? Define a fluid. What is meant by viscidity?—222. State one of the most obvious properties of fluids? On what do the peculiar mechanical properties of fluids depend? In what respect does the pressure of a fluid differ from that of a solid?—223. Into what two classes are fluids distinguished? What is an elastic fluid? What fluids come under this denomination? Give an instance of a gas, capable of assuming the liquid, and even the solid, form. How do vapours differ from air and gases? What bodies are generally considered inelastic?—224. Is water

an elastic, or non-elastic fluid? Describe Fig. 90, and show how water was found to be elastic? In what proportion does the bulk of water diminish under a pressure of 15,000 pounds to the square inch? In common experiments, is water considered elastic or non-elastic?—225. When water is confined, in what direction does it press? How does the experiment with the coffee-pot show that a small quantity of liquid will balance a large one?—226. Explain Fig. 92, and show how the pressure in the tube is equal to the pressure in the cistern.—227. What conclusion, or general truth, is to be drawn from these experiments?

228. What difference does the shape or size of a vessel make in respect to the pressure of a fluid on its bottom? Explain Fig. 93, and show how the equilibrium is produced. Suppose an ounce of water be poured into the tube A, what will be its effect on the contents of the other vessels? What conclusion is to be drawn from pouring the ounce of water into the tube A? —229. What is the reason that a large quantity of water will not force a small quantity above its own level?—230. Is the force of water in proportion to its height, or its quantity? How is a small quantity of water shown to press equal to a large quantity by Fig. 94? Explain the reason why the pressure is as great at D as at C.—231. How is the same principle illustrated by Fig. 95? How is the upward pressure of water illustrated by the same apparatus? Under the pressure of a column of water twenty feet high, what will be the height of the jet? Under a pressure of a hundred feet, how will it rise?

232. What is the hydrostatic bellows? What property of water is this instrument designed to show? Illustrate this property by the anatomical syphon.—233. Explain Fig. 97. Where is the piston? Which is the pump barrel, in which it works? In the hydrostatic press, what is the proportion between the pressure given by the small piston, and the force exerted on the large one? What is the estimated force which a man could give by means of one of these engines? If the pressure of two tons be made on a piston of a quarter of an inch in diameter, what will be the force transmitted to the other piston of three feet in diameter?

234. What is said of the pressure of water in the crevices of mountains, and the consequences?—235. What is the pressure on the bottom of a vessel, containing a fluid, equal to? Suppose the sides of the vessel slope outwards, what effect does this produce on the pressure?—236. Suppose the sides of the vessel slope inwards, what effect does this produce on the pressure? How is it shown that the pressure of the fluid at 5, is

equal to what it would have been had the fluid been perpendicular above that point?—237. What do we learn from what has been stated respecting the last two figures?

238. On what principle is the water level constructed? Describe the manner in which the level with *sights* is used, and the reason why the floats will always be at the same height. What is the use of the level?—239. Describe the common spirit level, and the method of using it.—240. Explain by Fig. 103, how an exact line may be obtained by adjusting the sights.

241. When a solid is weighed in water, why does it lose a part of its weight?—242. How much less will a cubic inch of any substance weigh in water than in air? How is it proved by Fig. 104 that a body weighs less in water than in air? What is the specific gravity of a body?—243. How are the specific gravities of solid bodies taken? Why does a heavy body weigh comparatively less in the water than a light one?—244. Having taken the difference between the weight of a body in air and in water, by what rule is its specific gravity found? Give the example stated, and shew how the difference between the specific gravities of platina and silver is ascertained.—245. How is the specific gravity of a *liquid* body ascertained? How is that of a *gaseous* body found.—246. How does the influence of gravity resemble that of cohesion in masses? Give examples of this influence, in opposing combination?

247. What is the hydrometer? Suppose a cubic inch of any substance weighs 253 grains less in water than in air, what is the actual weight of a cubic inch of water?—248. On what principle is the hydrometer founded? How is this instrument formed? How is the hydrometer prepared for use? How is it known, by this instrument, whether the fluid is lighter or heavier than water?—249. What is the standard by which the weights of other bodies are compared? What is the specific gravity of water? When it is said that the specific gravity of a body is 2, or 4, what meaning is intended to be conveyed? Alcohol has a specific gravity of 809; what, in reference to this, is the specific gravity of water?—250. How may it be shewn, by this instrument, how much water has been added to spirits? How may the adulteration of milk with water be detected?

251. In what manner is a syphon made? Explain the reason why the water ascends through one leg of the syphon, and descends through the other.—252. Prove that the action of the syphon depends on atmospheric pressure. What is an intermittent spring?—253. How is the phenomenon of the intermittent spring explained? Explain Fig. 107, and shew the reason why such a spring will flow and cease alternately.

CHAP. V.

OF HYDRAULICS.

254. "It has been stated, (§ 162,) that Hydrostatics is that branch of Natural Philosophy, which treats of the weight, pressure, and equilibrium of fluids; Hydraulics has for its object the investigation of the laws which regulate fluids in motion. If the pupil has learned the principles on which the pressure and equilibrium of fluids depend, as explained under the former chapter, he will now be prepared to understand the laws which govern fluids when in motion. The pressure of water downwards, is exactly in the same proportion to its height, as is the pressure of solids in the same direction. Suppose a vessel of three inches in diameter has a billet of wood set up in it, so as to touch only the bottom, and suppose the piece of wood to be three feet long, and to weigh nine pounds; then the pressure on the bottom of the vessel will be nine pounds. If another billet of wood be set on this of the same dimensions, it will press on its top with the weight of nine pounds, and the pressure at the bottom will be 18 pounds, and if another billet be set on this, the pressure at the bottom will be 27 pounds, and so on, in this ratio, to any height the column is carried.

255. "Now, the pressure of fluids is exactly in the same proportion; and when confined in pipes, may be considered as one short column set on another, each of which increases the pressure of the lowest in proportion to their number and height. Thus, notwithstanding the lateral pressure of fluids, their downward pressure is as their heights. This fact will be found of importance in the investigation of the principles of certain hydraulic machines, and we have therefore endeavoured to impress it on the mind of the pupil by Fig. 108, where it will be seen, that if the pressure of three feet of water be equal to nine pounds on the bottom of the vessel, the pressure of twelve feet will be equal to thirty-six pounds.

256. "The quantity of water which will be discharged from an orifice of a given size, will be in proportion to the height of the column of water above it, for the discharge will increase in velo-

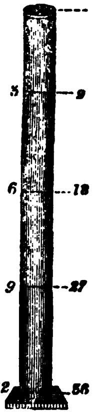


Fig. 108.

city, in proportion to the pressure, and the pressure, we have already seen, will be in a fixed ratio to the height. If a vessel such as that represented by Fig. 109, be filled with water, and three apertures be made in its side at the points E, F, and G, the fluid will be thrown out in jets, and will fall towards the earth, in the curved lines, E, F, and G. The reason why these curves differ in shape, is, that the fluid is acted on by two forces, namely, the pressure of water above the jet, which produces its velocity forward, and the action of gravity, which impels it downward. It therefore obeys the same laws that solids do when projected forward, and falls down in curved lines, the shapes of which depend on their relative velocities. The quantity of water discharged being in proportion to the pressure, that discharged from each orifice will differ in quantity, according to the height of water about it.

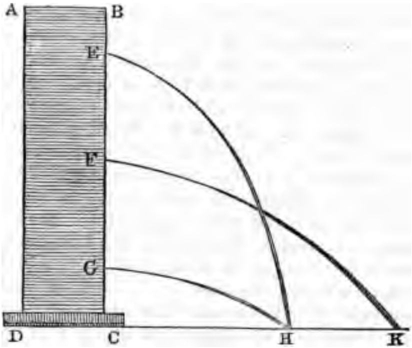


Fig. 109.

257. "It is found, however, that the velocity with which a vessel discharges its contents. does not depend entirely on the pressure, but in part on the kind of orifice through which the liquid flows. It might be expected, for instance, that a tin vessel of a given capacity, with an orifice of, say an inch, in diameter through its side, would part with its contents sooner than another of the same capacity and orifice, whose side was an inch or two thick, since the friction through the tin might be considered much less than that presented by the other orifice. But it has been found by experiment, that the

tin vessel does not part with its contents so soon as another vessel, of the same height and size of orifice, from which the water flowed through a short pipe. And, on varying the length of these pipes, it is found that the most rapid discharge, other circumstances being equal, is through a pipe, whose length is twice the diameter of its orifice. Such an aperture discharged 82 quarts, in the same time that another vessel of tin, without the pipe, discharged 62 quarts.

258. "This surprising difference is accounted for, by supposing that the cross currents, made by the rushing of the water from different directions towards the orifice, mutually interfere with each other, by which the whole is broken, and thrown into confusion by the sharp edge of the tin, and hence the water issues in the form of spray, or of a screw, from such an orifice. A short pipe seems to correct this contention among opposing currents, and to smooth the passage of the whole, and hence we may observe, that from such a pipe, the stream is round and well defined.

259. "*Proportion between the pressure and the velocity of discharge.*—If a small orifice be made in the side of a vessel filled with any liquid, the liquid will flow out with a force and velocity equal to the pressure which the liquid before exerted on that portion of the side of the vessel before the orifice was made. Now, as the pressure of fluids is as their heights, it follows, as above stated, that if several such orifices are made, the lowest will discharge the greatest, while the highest will discharge the least, quantity of the fluid. The velocity of discharge, in the several orifices of such a vessel, will show a remarkable coincidence between the ratio of increase in the quantity of liquid, and the increased velocity of a falling body. Thus, if the tall vessel, Fig 110, of equal dimensions throughout, be filled with water, and a small orifice be made at one inch from the top, or below the surface, as at 1; and another at 2, 4 inches below this; another at 9 inches; a fourth at 16 inches; and a fifth at 25 inches; then the velocities of discharge, from these several orifices, will be in the proportion of 1, 2, 3, 4, 5. To explain this more obviously, we will place the expressions of the several velocities in the upper line of the following table,

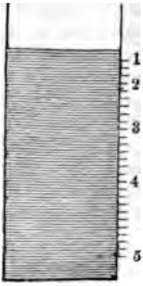


Fig. 110.

the lower numbers, corresponding, expressing the depths of the several orifices:—

Velocity,	1	2	3	4	5	6	7	8	9	10
Depth,	1	4	9	16	25	36	49	64	81	100

Thus it appears, that to produce a twofold velocity a fourfold height is necessary. To obtain a threefold velocity of discharge, a ninefold height is required, and for a fourfold velocity, sixteen times the height is necessary, and so in this proportion, as shown by the table.

260. "To apply this law to the motion of falling bodies, it appears that, if a body were allowed to fall freely from the surface of the water downwards, being unobstructed by the fluid, it would, on arriving at each of the orifices, have velocities proportional to those of the water discharged at the said orifices respectively. Thus, whatever velocity it would have acquired on arriving at 1, the first orifice, it would have doubled that velocity on arriving at 2, the second orifice, trebled it on arriving at the third orifice, and so on with respect to the others.

261. "In order to establish the remarkable fact, that the velocity with which a liquid spouts from an orifice in a vessel, is equal to the velocity which a body would acquire in falling unobstructed from the surface of the liquid to the depth of the orifice, it is only necessary to prove the truth of the principle in any one particular case. Now it is manifestly true, if the orifices be presented downwards, and the column of fluid over it be of small height, then this indefinitely small column will drop out of the orifice by the mere effect of its own weight, and, therefore, with the same velocity as any other falling body; but as fluids transmit pressure in all directions, the same effect will be produced whatever may be the direction of the orifice. Hence, if this principle be true, then the direction and size of the orifice can make no difference in the result, so that the principle, above explained, follows as an incontrovertible fact.

FRICTION BETWEEN SOLIDS AND FLUIDS.

262. "The rapidity with which water flows through pipes of the same diameter, is found to depend much on the nature

of their internal surfaces. Thus a lead pipe, with a smooth aperture, under the same circumstances, will convey much more water than one of wood, where the surface is rough, or beset with points. In pipes, even where the surface is as smooth as glass, there is still considerable friction, for in all cases, the water is found to pass more rapidly in the middle of the stream than it does on the outside, where it rubs against the sides of the tube. The sudden turns, or angles of a pipe, are also found to be a considerable obstacle to the rapid conveyance of the water, for such angles throw the fluid into eddies or currents by which its velocity is arrested. In practice, therefore, sudden turns are generally avoided, and where it is necessary that the pipe should change its direction, it is done by means of as large a circle as convenient.

263. "Where it is proposed to convey a certain quantity of water to a considerable distance in pipes, there will be a great disappointment in respect to the quantity actually delivered, unless the engineer take into account the friction, and the turnings of the pipes, and make large allowances for these circumstances. If the quantity to be actually delivered ought to fill a two inch pipe, one of three inches will not be too great an allowance, if the water is to be conveyed to any considerable distance. In practice, it will be found that a pipe of two inches in diameter, one hundred feet long, will discharge about five times as much water as one of one inch in diameter of the same length, and under the same pressure. This difference is accounted for, by supposing that both tubes retard the motion of the fluid, by friction, at equal distance from their inner surfaces, and consequently, that the effect of this cause is much greater in proportion, in a small tube, than in a large one.

264. "The effect of friction in retarding the motion of fluids is perpetually illustrated in the flowing of rivers and brooks. On the side of a river, the water, especially where it is shallow, is nearly still, while in the middle of the stream it may run at the rate of five or six miles an hour. For the same reason, the water at the bottoms of rivers is much less rapid than at the surface. This is often proved by the oblique

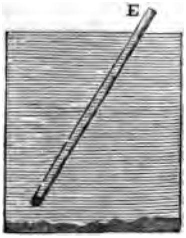


Fig. 111.

position of floating substances, which in still water would assume a vertical direction. Thus, suppose the stick of wood, E, Fig. 111, to be loaded at one end with lead, of the same diameter as the wood, so as to make it stand upright in still water. In the current of a river, where the lower end nearly reaches the bottom, it will incline as in the figure, because the water is more rapid towards the surface than at the bottom, and hence the tendency of the upper end to move faster than the lower one, gives it an inclination forward.

265. "The common pump, though a hydraulic machine, depends on the pressure of the atmosphere for its effect, and therefore its explanation comes properly under the article Pneumatics, where the consequences of atmospheric pressure will be illustrated. Such machines only, as raise water without the assistance of the atmosphere, come properly under the present article.

266. "*Archimedes's screw.*—Among these, one of the most curious, as well as ancient machines, is the *screw of Archimedes*, which was invented by that celebrated philosopher, two hundred years before the Christian era, and then employed for raising water and draining land in Egypt. It consists of a large tube, Fig. 112, coiled round a shaft of wood to keep it in place, and give it support. Both ends of the tube are open, the lower one being dipped into the water to be raised, and the upper one discharging it in an intermitting stream. The shaft turns on a support at each end, that at the upper end being seen at A, the lower one being hid by the water. As the machine now stands, the lower bend of the screw is filled with water, since it is below the surface C, D. On turning it by the handle, from left to

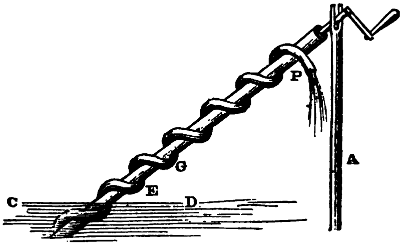


Fig. 112.

right, that part of the screw now filled with water will rise above the surface C, D, and the water having no place to escape, falls into the next lowest part of the screw at E. At the next revolution, that portion which, during the last was at E, will be elevated to G, for the lowest bend will receive another supply, which in the mean time will be transferred to E, and thus, by a continuance of this motion, the water is finally elevated to the discharging orifice P. This principle is readily illustrated by winding a piece of lead tube round a walking stick, and then turning the whole with one end in a dish of water, as shown in the figure.

267. "*Theory of Archimedes's screw.*—By the following cuts and explanations, the manner in which this machine acts will be understood. Suppose the extremity 1, Fig. 113, to be presented upwards, as in the figure, the screw itself being inclined as represented. Then, from its peculiar form and position, it is evident, that commencing at 1, the screw will descend until we arrive at a certain point 2; in proceeding from 2 to 3 it will ascend. Thus, 2 is a point so situated that the parts of the screw on both sides of it ascend, and therefore if any body, as a ball, were placed in the tube at 2, it could not move in either direction without ascending. Again, the point 3, is so situated, that the tube on each side of it descends; and as we proceed we find another point 4, which, like 2, is so placed, that the tube on both sides of it ascends, and, therefore, a body placed at 4, could not move without ascending. In like manner, there is a series of other points along the tube, from which it either descends or ascends, as is obvious by inspection. Now let us suppose a ball, less in size than the bore of the tube, so as to move freely in it, to be dropped in at 1. As the tube descends from 1 to 2, the ball of course will descend down to 2, where it will remain at rest.

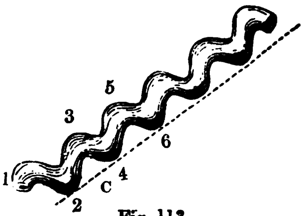


Fig. 113.

268. "Next, suppose the ball to be fastened to the tube at 2, and suppose the screw to be turned nearly half round, so that the end 1 shall be turned downwards, and the point 2 brought nearly to the highest point of the curve 1, 2, 3.

This movement of the spiral, it is evident, would change the positions of the ascending and descending parts, as represented by Fig. 114. The ball, which we supposed attached to the tube, is now nearly at the highest point at 2, and if detached, will descend down to 3, where it will rest. The point at which 2 was placed in the first position of the screw is marked by B, in the second position. The effect of turning the screw, therefore, will be to transfer the ball from the highest to the lowest point. Another half turn of the screw, will cause the ball to pass over another high point, and descend the declivity down to 5, in Fig. 114, where it will again rest.

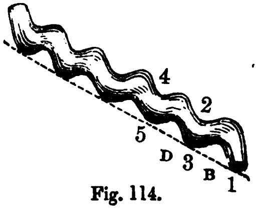


Fig. 114.

269. "It is unnecessary to explain the steps by which the ball would gain another point of elevation, since it is clear that by continuing the same process of action, and of reasoning, it would be plain that the ball would be gradually transferred from the lowest to the highest point of the screw.

270. "Now all that we have said with respect to the ball, would be equally true of a drop of water in the tube; and, therefore, if the extremity of the tube were immersed in water, so that the fluid, by its pressure or weight, be continually forced into the extremity of the screw, it would, by making it revolve, be gradually carried along the spiral to any height to which it might extend. It will, however, be seen, from the above explanation, that the tube must not be so elevated from the point of immersion, that the spirals will not descend from one point to another, in which case it is obvious that the machine will not act. If the tube be placed in a perpendicular position, the ball, instead of gaining an increased elevation by turning the screw, would descend to the ground. A certain inclination, therefore, depending on the course of the screw, must be given this machine, in order to ensure its action.

271. "Instead of this method, water was sometimes raised by the ancients, by means of a rope, or bundle of ropes, as shown at Fig. 115. This mode illustrates, in a very striking

manner, the force of friction between a solid and fluid, for it was by this force alone, that the water was supported and elevated. The large wheel A, is supposed to stand over the well, and B, a smaller wheel, is fixed in the water. The rope is extended between the two wheels, and rises on one side in a perpendicular direction. On turning the wheel by the crank C, the water is brought up by the friction of the rope, and falling into a reservoir at the bottom of the frame which supports the wheel, is discharged at the spout D. It is evident that the motion of the wheel, and consequently that of the rope, must be very rapid, in order to raise any considerable quantity of water by this method. But when the upward velocity of the rope is eight or ten feet per second, a large quantity of water may be elevated to a considerable height by this machine.

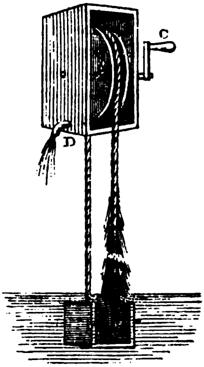


Fig. 115.

272. "*Barker's mill.*—For the different modes of applying water as a power for driving mills, and other useful purposes, we must refer the reader to works on practical mechanics. There is, however, one method of turning machinery by water, invented by Dr Barker, which is strictly a philosophical, and at the same time a most curious invention, and therefore is properly introduced here. This machine is called *Barker's centrifugal mill*, and such parts of it as are necessary to understand the principle on which it acts are represented by Fig. 116.

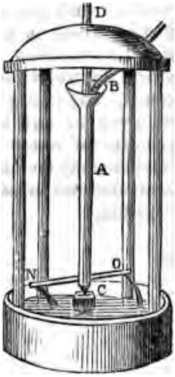


Fig. 116.

273. "The upright cylinder A, is a tube which has a funnel-shaped mouth, for the admission of the stream of water from the pipe B. This tube is six or eight inches in diameter, and may be from ten to twenty feet long. The arms N and O, are also tubes, communi-

cating freely with the upright one, from the opposite sides of which they proceed. The shaft D is firmly fastened to the inside of the tube, openings at the same time being left for the water to pass to the arms O and N. The lower part of the tube is solid, and turns on a point resting on the block of stone or iron C. The arms are closed at their ends, near which there are orifices on the sides opposite to each other, so that the water spouting from them will fly in opposite directions. The stream from the pipe B is regulated by a stop-cock, so as to keep the tube A constantly full, without overflowing.

274. "To set this engine in motion, suppose the upright tube to be filled with water, and a slight impulse to be given to the arms, N and O, the pressure of the water from the perpendicular column in the large tube will give the fluid a velocity of discharge at the ends of the arms proportionate to its height. The reaction which is produced by the flowing of the water on the points behind the discharging orifice will continue, and increase the rotatory motion thus begun. After a few revolutions, the machine will receive an additional impulse by the centrifugal force generated in the arms, and, in consequence of this, a much more violent and rapid discharge of the water takes place, than would occur by the pressure of that in the upright tube alone. The centrifugal force, and the force of the discharge thus acting at the same time, and each increasing the force of the other, this machine revolves with great velocity, and proportionate power. The friction which it has to overcome, when compared with that of other machines, is very slight, being chiefly at the point C, where the weight of the upright tube and its contents is sustained. By fixing a cog-wheel to the shaft at D, motion may be given to any kind of machinery required. Where the quantity of water is small, but its height considerable, this machine may be employed to great advantage, it being under such circumstances one of the most powerful engines ever invented."

QUESTIONS ON CHAP. V.

254. How does the science of Hydrostatics differ from that of Hydraulics? Does the downward pressure of water differ from the downward pressure of solids, in proportion?—255. How is the downward pressure of water illustrated? Without reference to the lateral pressure, in what proportion do fluids press downwards?—256. What will be the proportion of a fluid discharged from an orifice of a given size? Why do the lines described by the jets from the vessel, Fig. 109, differ in shape? What two forces act upon the fluid as it is discharged, and how do these forces produce a curved line?—257. Does the velocity with which a fluid is discharged depend entirely on the pressure? What circumstance besides pressure facilitates the discharge of water from an orifice? In a tube discharging water with the greatest velocity, what is the proportion between its diameter and its length?—258. What is the proportion between the quantity of fluid discharged through an orifice of tin, and through a short pipe?—259. What are the proportions between the velocities of discharge and the heights of the orifices, as above explained? How is it proved that the velocity of the spouting liquid is equal to that of a falling body? What height is necessary to produce a twofold velocity? In what proportion does the height increase with respect to the velocity?—260. How is this law applied to the motion of falling bodies?—261. How is it shown that tho direction and size of the orifice can make no difference in the result?

262. Suppose a lead and a glass tube, of the same diameter, which will deliver the greater quantity of liquid in the same time? Why will a glass tube deliver most? What is said of the sudden turnings of a tube, in retarding the motion of the fluid?—263. How much more water will a two-inch tube of a hundred feet long discharge than a one inch tube of the same length? How is this difference accounted for?—264. How do rivers shew the effect of friction in retarding the motion of their waters?

266. Explain the screw of Archimedes, as represented in Fig. 112, and show how water is elevated by turning it. How may the principle of Archimedes's screw be readily illustrated?—267. Explain the manner in which a ball would ascend, Fig. 113, by turning the screw.—270. What is said concerning the inclination of the tube, in order to insure its action.—271. Explain in what manner water is raised by the machine represented by Fig. 115. —272. What is Fig. 116 intended to represent? Describe this mill.

CHAP. VI.

OF PNEUMATICS.

275. "The term Pneumatics is derived from the Greek *Pneuma*, which signifies *breath*, or *air*. It is that science which investigates the mechanical properties of air, and other elastic fluids. Under the article *Hydrostatics*, (§ 223,) it was stated that fluids were of two kinds, namely, *elastic* and *inelastic*, and that air and the gases belonged to the first kind, while water and other liquids belonged to the second. The atmosphere which surrounds the earth, and in which we live, and a portion of which we take into our lungs at every breath, is called *air*, while the artificial products which possess the same mechanical properties, are called *gases*. When, therefore, the word *air* is used, it will be understood to mean the atmosphere which we breathe. Every hollow, crevice, or pore, in solid bodies, not filled with a liquid, or some other substance, appears to be filled with air: thus, a tube of any length, the bore of which is as small as it can be made, if kept open, will be filled with air; and hence, when it is said that a vessel is filled with air, it is only meant that the vessel is in its ordinary state. Indeed, this fluid finds its way into the most minute pores of all substances, and cannot be expelled and kept out of any vessel, without the assistance of the air-pump, or some other mechanical means.

276. "By the *elasticity* of air, is meant its spring, or the force with which it re-acts, when compressed in a close vessel. It is chiefly in respect to its elasticity and lightness, that the mechanical properties of air differ from those of water, and other liquids. Elastic fluids differ from each other in respect to the *permanency* of the elastic property. Thus, steam is elastic only while its heat is continued, and on cooling, returns again to the form of water. Some of the gases also, on being strongly compressed, lose their elasticity, and take the form of liquids. But air differs from these, in being permanently elastic; that is, if it be compressed with ever so much force, and retained under compression for any length of time, it does not therefore lose its elasticity, or disposition to regain its former bulk, but always re-acts with a force in proportion to the power by which it is compressed.

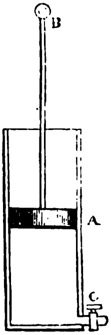


Fig. 117.

277. "Thus, if the strong tube, or barrel, Fig. 117, be smooth, and equal on the inside, and there be fitted to it the solid piston, or plug A, so as to work up and down air tight, by the handle B, the air in the barrel may be compressed into a space a hundred times less than its usual bulk. Indeed, if the vessel be of sufficient strength, and the force employed sufficiently great, its bulk may be lessened a thousand times, or in any proportion, according to the force employed; and if kept in this state for years, it will regain its former bulk the instant the pressure is removed. Thus, it is a general principle in Pneumatics, that air is compressible in proportion to the force employed.

278. "On the contrary, when the usual pressure of the atmosphere is removed from a portion of air, it expands and occupies a space larger than before; and it is found by experiment, that this expansion is in a ratio, as the removal of the pressure is more or less complete. Air also expands or increases in bulk, when heated. If the stop-cock C, Fig. 117, be opened, the piston A may be pushed down with ease, because the air contained in the barrel will be forced out at the aperture. Suppose the piston to be pushed down to within an inch of the bottom, and then the stop-cock closed, so that no air can enter below it. Now, on drawing the piston up to the top of the barrel, the inch of air will expand, and fill the whole space, and were this space a thousand times as large, it would still be filled with the expanded air, because the piston removes the pressure of the external atmosphere from that within the barrel. It follows, therefore, that the space which a given portion of air occupies, depends entirely on circumstances. If it is under pressure, its bulk will be diminished in exact proportion; and as the pressure is removed, it will expand in proportion, so as to occupy a thousand, or even a million times as much space as before.

279. "Another property which air possesses is weight, or gravity. This property, it is obvious, must be slight, when compared with the weight of other bodies. But that air has a certain degree of gravity in common with other ponderous substances, is proved by direct experiment. Thus, if the air be pumped out of a close vessel, and then the vessel be ex-

actly weighed, it will be found to weigh more when the air is again admitted.

280. "*Pressure of the atmosphere.*—It is, however, the weight of the atmosphere which presses on every part of the earth's surface, and in which we live and move, as in an ocean, that here particularly claims our attention. The pressure of the atmosphere may be easily shown by the tube and piston, Fig. 118. Suppose there is an orifice to be opened or closed by the valve B, as the piston A is moved up or down in its barrel. The valve being fastened by a hinge on the upper side, on pushing the piston down, it will open by the pressure of the air against it, and the air will make its escape. But when the piston is at the bottom of the barrel, on attempting to raise it again, towards the top, the valve is closed by the force of the external air acting upon it. If, therefore, the piston be drawn up in this state, it must be against the pressure of the atmosphere, the whole weight of which, to an extent equal to the diameter of the piston, must be lifted, while there will remain a vacuum or void space below it in the tube. If the piston be only three inches in diameter, it will require the full strength of a man to draw it to the top of the barrel, and when raised, if suddenly let go, it will be forced back again by the weight of the air, and will strike the bottom with great violence.

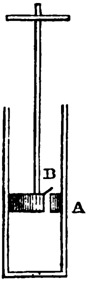


Fig. 118.

281. "Supposing the surface of a man to be equal to 14½ square feet, and allowing the pressure on each square inch to be 15lbs., such a man would sustain a pressure on his whole surface equal to nearly 14 tons.

282. "Now, that it is the weight of the atmosphere which presses the piston down, is proved by the fact, that if its diameter be enlarged, a greater force, in exact proportion, will be required to raise it. And further, if, when the piston is drawn to the top of the tube, a stop-cock, as at Fig. 118, be opened, and the air admitted under it, the piston will not be forced down in the least, because then the air will press as much on the under, as on the upper side of the piston.

283. "By accurate experiments, an account of which it is not necessary here to detail, it is found that the weight of the atmosphere on every inch square of the surface of the earth is equal to fifteen pounds. If, then, a piston working

air tight in a barrel, be drawn up from its bottom, the force employed, besides the friction, will be just equal to that required to lift the same piston, under ordinary circumstances, with a weight laid on it equal to fifteen pounds for every square inch of surface. The number of square inches in the surface of a piston of a foot in diameter, is 113. This being multiplied by the weight of the air on each inch, which is 15 pounds, is equal to 1695 pounds. Thus the air constantly presses on every surface, which is equal to the dimensions of a circle one foot in diameter, with a weight of 1695 pounds.

AIR-PUMP.

284. "The *air-pump* is an engine by which the air can be pumped out of a vessel, or withdrawn from it. The vessel so exhausted, is called a *receiver*, and the space thus left in the vessel, after withdrawing the air, is called a *vacuum*. The principles on which the air-pump is constructed are readily understood, and are the same in all instruments of this kind, though the form of the instrument itself is often considerably modified. The general principles of its construction will be comprehended by an explanation of Fig. 119. In this figure, let R be a glass vessel, or receiver, closed at the top, and open at the bottom, standing on a perfectly smooth plate of metal called the *plate* of the air-pump. Through the plate is an aperture, P, which communicates with the inside of the receiver, and the barrel of the pump. The piston moves air tight through the barrel.

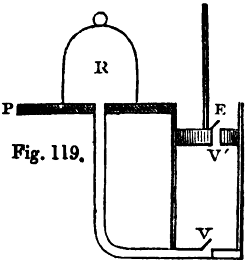


Fig. 119.

285. "Now suppose the piston to be drawn up, it will then leave a free communication between the receiver R, through the orifice, to the pump barrel in which the piston works. Then if the piston be forced down by its handle, it will compress the air in the barrel between V′ and V, and, in consequence, the valve E will be opened, and the air so condensed will be forced out. On drawing the piston up again, the valve will be closed, and the external air not being permitted to enter, a vacuum will be formed in the barrel, from V′ to V. When the piston comes again to the top of the bar-

rel, the air contained in the glass vessel, together with that in the passage between the vessel and the pump barrel, will rush in to fill the vacuum. Thus, there will be less air in the whole space, and consequently in the receiver, than at first, because all that was contained in the barrel is forced out at every stroke of the piston. On repeating the same process, that is, drawing up and forcing down the piston, the air at each time in the receiver, will become less and less in quantity, and, in consequence, more and more rarefied. For it must be understood, that although the air is exhausted at every stroke of the pump, that which remains, by its elasticity, expands, and still occupies the whole space. The quantity forced out at each successive stroke is therefore diminished, until, at last, it no longer has sufficient force before the piston to open the valve, when the exhausting power of the instrument must cease entirely. Now, it will be obvious, that as the exhausting power of the air-pump depends on the expansion of the air within it, a *perfect* vacuum can never be formed by its means, for so long as exhaustion takes place, there must be air to be forced out, and when this becomes so rare as not to force open the valves, then the process must end."

286. This limitation to the exhausting power of the air-pump, as above described, induced Mr Charles Chalmers, of the Merchiston Academy, to adopt the following modification of the machine. Fig. 120 represents Mr Chalmers' air-pump, in which R is a tube connected with that leading to the receiver (not shewn in the figure); there is a valve, V, at the bottom of the cylinder, and another, V′, in the piston, P, both opening downward; the piston works air-tight through a collar of leather at the top of the cylinder. The tube R being connected with the receiver, the process of withdrawing the air from it will proceed as follows:—When the piston P is pressed down to the bottom of the cylinder, all the air which it contained will be forced out at V. When the piston is drawn up, the valve, V, closes, preventing the entrance of air from the atmosphere; and whenever the piston passes the tube R, the air immediately rushes into the cylinder, in conse-

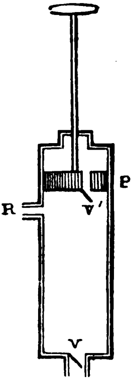


Fig. 120.

quence of its elasticity, from the receiver; another descent of the piston expels this volume of air, and thus the action goes on. A valve v′ in the piston prevents any accumulation of the air in the cylinder, after the piston rises above R, and enables it to act smoothly and equally. By this simple contrivance the process of exhaustion may go on indefinitely, there being *no valve of any kind* between the cylinder and the receiver.

287. "A good air-pump has two similar pumping barrels to that described, so that the process of exhaustion is performed in half the time that it could be performed by one barrel. The barrels, with their pistons, and the usual mode of working them, are represented by Fig. 121. The piston rods are furnished with racks, or teeth, and are worked by the toothed wheel *a*, which is turned backwards and forwards, by the lever and handle *b*. The exhaustion pipe *c*, leads to the plate on which the receiver stands, as shown in Fig. 121. The valves *v*, *n*, *u*, and *m*, all open upwards.

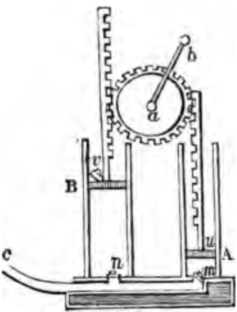


Fig. 121.

288. "To understand how these pistons act to exhaust the air from the vessel on the plate, through the pipe *c*, we will suppose, that as the two pistons now stand, the handle *b* is to be turned towards the left. This will raise the piston A, while the valve *u* will be closed by the pressure of the external air acting on it in the open barrel in which it works. There would then be a vacuum formed in this barrel, did not the valve *m* open, and let in the air coming from the receiver, through the pipe *c*. When the piston, therefore, is at the upper end of the barrel, the space between the piston and the valve *m*, will be filled with the air from the receiver. Next, suppose the handle to be moved to the right, the piston A will then descend, and compress the air with which the barrel is filled, which, acting against the valve *u*, forces it open, and thus the air escapes. Thus, it is plain, that every time the piston rises, a portion of air, however rarefied, enters the barrel, and every time that it descends, this portion escapes, and mixes with the external atmosphere. The action of the other piston is exactly similar to this,

only that B rises while A falls, and so the contrary. It will appear, on an inspection of the figure, that the air cannot pass from one barrel to the other, for while A is rising, and the valve *m* is open, the piston B will be descending, so that the force of the air in the barrel B, will keep the valve *n* closed. Many interesting and curious experiments, illustrating the expansibility and pressure of the atmosphere, are shown by this instrument.

289. "(1.) If a withered apple be placed under the receiver, and the air be exhausted, the apple will swell and become plump, in consequence of the expansion of the air which it contains within the skin.

"(2.) Ether, placed in the same situation, soon begins to boil without the influence of heat, because its particles, not having the pressure of the atmosphere to force them together, fly off with so much rapidity as to produce ebullition."

(3.) If a bladder, partly filled with air, and tied tightly at the neck, be placed under the receiver, and a vacuum be then produced, the air in the bladder will expand by removal of the external pressure, and perhaps burst the bladder.

(4.) Any small animal, as a mouse or bird, placed in the exhausted receiver, will immediately die, from want of breath, and from the expansion of its body.

(5.) If a long-necked flask be inverted in a vessel of water, and this apparatus be placed under the receiver, and the air rarefied by means of the pump, the air in the flask will expand and escape through the water, and, on re-admitting the atmosphere, the water will rise in the flask, and occupy the space formerly occupied by the air.

(6.) If a lighted taper be placed under a receiver, and this be rapidly exhausted, the flame will be extinguished much sooner than it would have been had the receiver been filled with air. It is upon the same principle that, in a vacuum, no light is produced by the collision of a flint and steel.

THE CONDENSER.

290. "The operation of the *condenser* is the reverse of that of the air-pump, and is a much more simple machine. The air-pump, as we have just seen, will deprive a vessel of its ordinary quantity of air. The condenser, on the contrary, will double or treble the ordinary quantity of air in a close vessel, according to the force employed.

291. "This instrument, Fig. 122, consists of a pump barrel

and piston A, a stop-cock B, and the vessel C furnished with a valve opening inwards. The orifice D is to admit the air, when the piston is drawn up to the top of the barrel. To describe its action, let the piston be above D, the orifice being open, and therefore the instrument filled with air, of the same density as the external atmosphere. Then, on forcing the piston down, the air in the pump barrel, below the orifice D, will be compressed, and will rush through the stop-cock B, into the vessel C, where it will be retained, because, on again moving the piston upward, the elasticity of the air will close the valve through which it was forced. On drawing the piston up again, another portion of air will rush in at the orifice D, and on forcing it down, this will also be driven into the vessel C; and this process may be continued as long as sufficient force is applied to move the piston, or there is sufficient strength in the vessel to retain the air. When the condensation is finished, the stop-cock B may be turned, to render the confinement of the air more secure.

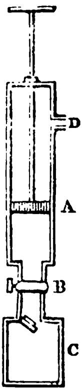


Fig. 122.

292. "The magazines of *air-guns* are filled in the manner above described. The air-gun is shaped like other guns, but instead of the force of powder, that of air is employed to project the bullet. For this purpose, a strong hollow ball of copper, with a valve on the inside, is screwed to a condenser, and the air is condensed in it, thirty or forty times. This ball or magazine is then taken from the condenser, and screwed to the gun, under the lock. By means of the lock, a communication is opened between the magazine, and the inside of the gun-barrel, on which the spring of the confined air against the leaden bullet is such, as to throw it with nearly the same force as gunpowder."

CONSTITUTION OF THE ATMOSPHERE.

293. The influence of the atmospheric pressure on the phenomenon of ebullition, has been already noticed (§ 148). It is now necessary to add a few remarks on the constitution and properties of the atmosphere. The air which surrounds our globe is considered to consist of a *mechanical mixture* of oxygen and nitrogen gases, which are always present in the same proportions. One hundred parts, by weight, of atmo-

spheric air contain 23.1 parts of oxygen, and 76.9 parts of nitrogen; or 100 volumes of air contain nearly 21 volumes of oxygen gas. From the extensive range of affinity which the latter gas possesses, it is obvious, that, were it alone to constitute our atmosphere, and to be left unchecked to exert its powerful effects, the world would run through its stages of decay, renovation, and final destruction, in a rapid cycle. Combustion, once excited, would proceed with ungovernable violence; the globe would undergo a general conflagration, while the functions of animal life would proceed with fearful intensity, and terminate their brief career in a few hours. It is on this account that nitrogen is present in the air in so large a proportion. This gas is peculiarly adapted to this purpose, as it possesses no disposition to combine with oxygen, and exerts no influence on the processes which are taking place on the earth. The properties of the atmosphere are much affected by the presence of *watery vapour*, which it acquires by contact with the surface of the ocean, rivers, lakes, and damp soil. The quantity which it contains is limited by its temperature, and it is again condensed and precipitated, from various causes, in the form of dew, rain, &c. (§ 145).

294. There is yet another ingredient of atmospheric air, viz., *carbonic acid;* this may be observed by exposing to the air a vessel of lime water, which will presently be covered over with a film of carbonate of lime. Saussure found carbonic acid in the air collected at the top of Mont Blanc; and there can be no doubt of its being diffused through the whole mass of the atmosphere. The *mean* proportion of carbonic acid is 4.9 volumes in 10,000 volumes of air, or almost exactly 1 in 2000 volumes; but it is found to vary in the same place within short intervals of time; the variations ranging from 6.2 as a *maximum* to 3.7 as a *minimum* in 10,000 volumes of air. The proportion is greater in summer than in winter, greater during night than in day time, and greater in gloomy than in clear weather. It is also more abundant in elevated than in low situations; but in the former, its quantity is nearly the same by day and night, in wet and in dry weather; whereas in the latter, its quantity is diminished by the moist state of the ground, as after rain. The presence of carbonic acid in the atmosphere is essential to vegetable life; *plants* absorb this gas during the day, decompose it within their tissues, and appropriate the carbon for their support, while they evolve the oxygen with which it was combined. During

night opposite effects are produced: oxygen is absorbed, and carbonic acid evolved. But it has been shown that plants, during twenty-four hours, yield more oxygen than they consume. Carbonic acid is discharged in immense quantities from the active volcanoes in America, and from many of the mineral springs which abound in various parts of Europe; it is also generated during the combustion and decay of organic matter.

295. Atmospheric air is 815 times lighter than water, and 11,065 times lighter than mercury. According to Dr Prout, 100 cubic inches of atmospheric air, deprived of its aqueous vapour and the small quantity of carbonic acid it contains, weigh 31.0117 grains, at the temperature of 60°, and when the barometer stands at 30 inches. Its bulk varies with the temperature and pressure by which it is affected, according to the laws which regulate other gases (§ 133, 152). Atmospheric air is highly compressible and elastic. It has been found that the volume of air, as of all other gaseous bodies, so long as they retain the elastic state, is inversely as the pressure to which it is subjected. Thus, 100 volumes of air, under a pressure of one pound, are reduced to 50 volumes under a pressure of two pounds, and expand to 200 volumes under a pressure of only half a pound.

296. The *temperature of the atmosphere* varies with its elevation. It is greatest at the surface of the earth, and diminishes one degree for every 352 feet of elevation, in the lower strata; at great distances, the progressive fall of temperature is less rapid. In the warmest climates, there is some point, at which the thermometer never rises above 32°; this point varies with the latitude, being highest within the tropics, and gradually descending in the direction of the poles. This diminution of temperature with elevation from the surface of the earth, appears to depend upon the joint influence of the *two following causes.* 1. The atmosphere derives its heat, not from the rays of the sun, but from the earth; its temperature is therefore lower, the further it is removed from this source of heat. 2. The increased rarity of the atmosphere in high elevations, is accompanied by the production of cold, owing to its specific heat being greater in a rarefied than in a more condensed state (§ 161). The phenomena of *winds* (§ 122) are occasioned by inequality of temperature of the atmosphere at different points of the earth's surface.

297. *Atmospheric pressure.*—We are now in a condition to

make further inquiries into the phenomena of atmospheric pressure. "Suppose A, Fig. 123, to be a long tube, with the piston, B, so nicely fitted to its inside, as to work air-tight. If the lower end of the tube be dipped into water, and the piston drawn up, by pulling at the handle, C, the water will will follow the piston so closely as to be in contact with its surface, and apparently to be drawn up by the piston, as though the whole was one solid body. If the tube be thirty-five feet long, the water will continue to follow the piston, until it comes to the height of about thirty-three feet, where it will stop; and if the piston be drawn up still farther, the water will not follow it, but will remain stationary, the space from this height, between the piston and the water being left a void space, or vacuum. The rising of the water in the above case, which only involves the principle of the common pump, is thought by some to be caused by *suction*, the piston *sucking* up the water as it is drawn upward. But, according to the common notion attached to this term, there is no reason why the water should not continue to rise above the thirty-three feet, or why the power of suction should cease at that point, rather than at any other.

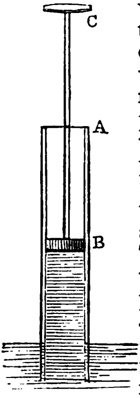


Fig. 123.

298. "Without entering into any discussion on the absurd notions concerning the power of suction, it is sufficient here to state, that it has long since been proved, that the elevation of the water in the case above described, depends entirely on the weight and pressure of the atmosphere, on that portion of the fluid which is on the outside of the tube. Hence, when the piston is drawn up, under circumstances where the air cannot act on the water around the tube, or pump-barrel, no elevation of the fluid will follow. This will be obvious by the following experiment:—Suppose Fig. 124 to be the sections or halves of two tubes, one within the other, the outer one being made entirely close, so as to admit no air, and the space between the two being also made air-tight at the top. Suppose, also, that the inner tube being left open at the lower end, does not reach the bottom of the outer tube, and thus that an open space be left between the two tubes every where, except at their upper ends, where they are

fastened together; and suppose that there is a valve in the piston, opening upwards, so as to let the air which it contains escape, but which will close on drawing the piston upwards. Now let the piston be at A, and in this state pour water through the stop-cock, C, until the inner tube is filled up by the piston, and the space between the two tubes filled up to the same point, and then let the stop-cock be closed. If, now, the piston be drawn up to the top of the tube, the water will not follow it, as in the case first described; it will only rise a few inches, in consequence of the elasticity of the air above the water, between the tubes, and in the space above the water there will be formed a vacuum between the water and the piston, in the inner tube.

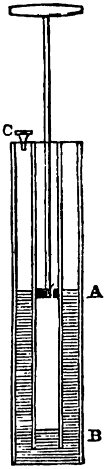


Fig. 124.

299. "The reason why the result of this experiment differs from that before described, is, that the outer tube prevents the pressure of the atmosphere from forcing the water up the inner tube as the piston rises. This may be instantly proved, by opening the stop-cock, C, and permitting the air to press upon the water, when it will be found, that as the air rushes in, the water will rise and fill the vacuum up to the piston. For the same reason, if a common pump be placed in a cistern of water, and the water is frozen over on the surface, so that no air can press upon the fluid, the piston of the pump might be worked in vain, for the water would not, as usual, obey its motion.

300 "It follows, as a certain conclusion from such experiments, that when the lower end of a tube is placed in water, and the air from within is removed by drawing up the piston, it is the pressure of the atmosphere on the water around the tube which forces the fluid up to fill the space thus left by the air. It is also proved that the weight or pressure of the atmosphere is equal to the weight of a perpendicular column of water 33 feet high, for it is found (Fig. 123) that the pressure of the atmosphere will not raise the water more than 33 feet, though a perfect vacuum be formed to any height above this point. Experiments on other fluids prove that this is the weight of the atmosphere, for if the end of a tube be dipped in any fluid, and the air be removed from the tube, above the fluid, it will rise to a greater or less height

than water, in proportion as its specific gravity is less or greater than that of water.

301. "*Mercury*, or *quicksilver*, has a specific gravity about 13½ times greater than that of water, and mercury is found to rise about 29 inches in a tube under the same circumstances that water rises 33 feet. Now 33 feet is 396 inches, which, being divided by 29, gives nearly 13½, so that mercury being 13½ times heavier than water, the water will rise under the same pressure 13½ times higher than the mercury.

THE BAROMETER.

302 "*Construction of the barometer.*—The *barometer* is constructed on the principle of atmospheric pressure. This term is compounded of two Greek words, *baros*, weight, and *metron*, measure, the instrument being designed to *measure the weight* of the atmosphere. Its construction is simple, and easily understood. It is merely a tube of glass nearly filled with mercury, with its lower end placed in a vessel of the same fluid, and the upper end furnished with a scale, to measure the height of the mercury. Let A, Fig. 125, be such a tube, 34 or 35 inches long, closed at one end, and open at the other. To fill the tube, set it upright, and pour the mercury in at the open end, and when it is entirely full, place the forefinger forcibly on this end, and then plunge the tube and finger under the surface of the mercury, before prepared in the vessel B. Then withdraw the finger, taking care that in doing this, the end of the tube is not raised above the mercury in the vessel. When the finger is removed, the mercury will descend four or five inches, and after several vibrations, up and down, will rest at an elevation of 29 or 30 inches above the surface of that in the vessel, as at C. Having fixed a scale to the upper part of the tube, to indicate the rise and fall of the mercury, the barometer would be finished, if intended to remain stationary. It is usual, however, to have the tube inclosed in a mahogany or brass case, to prevent its breaking, and to have the vessel closed on the top, and fastened to the tube, so that it can be transported without danger of spilling the mercury.

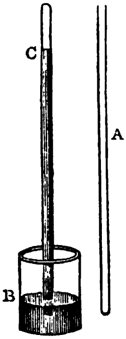


Fig. 125.

303. "The vessel of the portable barometer also differs

from that described, for were the mercury inclosed on all sides in a vessel of wood, or brass, the air would be prevented from acting upon it, and therefore the instrument would be useless. To remedy this defect, and still have the mercury perfectly inclosed, the bottom of the vessel is made of leather, which being elastic, the pressure of the atmosphere acts upon the mercury in the same manner as though it was not inclosed at all. Below the leather bottom there is a round plate of metal an inch in diameter, which is fixed on the top of a screw, so that when the instrument is to be transported, by elevating this piece of metal, the mercury is thrown up to the top of the tube, and thus kept from playing backwards and forwards, when the barometer is in motion.

304. "A person not acquainted with the principle of the instrument, on seeing the tube turned bottom upwards, will be perplexed to understand why the mercury does not follow the common law of gravity, and descend into the vessel. Were the tube of glass 33 feet high, and filled with water, the lower end being dipped into a tumbler of the same fluid, the wonder would be still greater. But as philosophical facts, one is no more wonderful than the other, and both are readily explained by the principles above illustrated.

305. "It has already been shewn that it is the pressure of the atmosphere on the fluid around the tube, by which the fluid within it is forced upward, when the pump is exhausted of its air. The pressure of the air, we have also seen, is equal to a column of water 33 feet high, or of a column of mercury 29 inches high. Suppose then a tube 33 feet high is filled with water, the air would then be entirely excluded, and were one of its ends closed, and the other end dipped in water, the effect would be the same as though both ends were closed, for the water would not escape, unless the air were permitted to rush in and fill up its place. The upper end being closed, the air could gain no access in that direction, and the open end being under water, is equally secure. The quantity of water in which the end of the tube is placed, is not essential, since the pressure of a column of water an inch in diameter, provided it be 33 feet high, is just equal to a column of air of an inch in diameter, of the whole height of the atmosphere. Hence the water on the outside of the tube serves merely to guard against the entrance of the external air.

306. "The same happens to the barometer-tube, when filled with mercury. The mercury, in the first place, fills

the tube perfectly, and therefore entirely excludes the air, so that when it is inverted in the cup, all the space above 29 inches is left a vacuum. The same effect precisely would be produced, were the tube exhausted of its air, and the open end placed in the cup: the mercury would run up the tube 29 inches, and then stop, all above that point being left a vacuum. The mercury, therefore, is prevented from falling out of the tube, by the pressure of the atmosphere on that which remains in the cup; for if this be removed, the air will enter, while the mercury will instantly begin to descend.

307. "In the barometer, above described, the rise and fall of the mercury is indicated by a scale of inches, and tenths of inches, fixed behind the tube; but it has been found that very slight variations in the density of the atmosphere are not readily perceived by this method. It being, however, desirable that these minute changes should be rendered more obvious, a contrivance for increasing the scale, called the *wheel* barometer, was invented. The whole length of the tube of the wheel barometer, Fig. 126, from C to A, is 34 or 35 inches, and it is filled with mercury as usual. The mercury rises in the short leg to the point O, where there is a small piece of glass floating on its surface, to which there is attached a silk string, passing over the pulley P. To the axis of the pulley is fixed an index or hand, and behind this is a graduated circle, as seen in the figure. It is obvious, that a very slight variation in the height of the mercury at O, will be indicated by a considerable motion of the index, and thus changes in the weight of the atmosphere hardly perceptible by the common barometer, will become quite apparent by this.

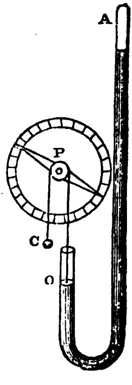


Fig. 126.

308. "The mercury in the barometer tube being sustained by the pressure of the atmosphere, and its medium altitude at the surface of the earth being about 29 inches, it might be expected that if the instrument were carried to a height from the earth's surface, the mercury would suffer a proportionate fall, because the pressure must be less, at a distance from the earth than at its surface, and experiment proves this to be the case. When, therefore, this instrument is elevated to any consi-

derable height, the descent of the mercury becomes perceptible. Even when it is carried to the top of a hill, or high tower, there is a sensible depression of the fluid, so that the barometer is employed to measure the heights of mountains,* and the elevation to which balloons ascend from the surface of the earth. On the top of Mont Blanc, which is about 16,000 feet above the level of the sea, the medium elevation of the mercury in the tube is only 14 inches, while, on the surface of the earth, as above stated, it is 29 inches.

309. "The medium range of the barometer in several countries, has generally been stated to be about 29 inches. It appears, however, from observations made at Cambridge, in Massachusetts, for 22 years, that its range there was nearly 30 inches.

310. "*Uses of the barometer.*—While the barometer stands in the same place, near the level of the sea, the mercury seldom or never falls below 28 inches, or rises above 31 inches, its whole range, while stationary, being only about 3 inches.

311. "These changes in the weight of the atmosphere indicate corresponding changes in the weather, for it is found, by watching these variations in the height of the mercury, that when it falls, cloudy or falling weather ensues, and that when it rises, fine clear weather may be expected. During the time when the weather is damp and lowering, and the smoke of chimneys descends towards the ground, the mercury remains depressed, indicating that the weight of the atmosphere during such weather is less than it is when the sky is clear. This contradicts the common opinion, that

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* The principle of the application of the barometer to the measurement of heights is identical with that of the sounding line. "In both cases we measure the distance of the point, whose level we would know from the surface of an equilibrated ocean: only in the one case it is an ocean of water; in the other, of air; in the one case our sounding line is real and tangible; in the other an imaginary one, measured by the length of the column of quicksilver, which the superincumbent air is capable of counterbalancing. The atmosphere possesses all the properties of a fluid really essential to the purpose in view, and this in particular,—that, over the whole surface of the globe, its *strata of equal density* are parallel to the surface of equilibrium, or to what *would be* the surface of the sea, if *prolonged under the continents*, and therefore each or any of them has all the characters of a definite surface to measure from. Now the weight at which, at any station, the mercury in a barometer is supported, informs us *at once* how much of the atmosphere is incumbent on that station; in other words, *in what stratum* of the general atmosphere (indicated by its density), the station is situated; whence we are enabled finally to conclude, by mechanical reasoning, at what height above the sea-level *that degree of density* is to be found over the whole surface of the globe."—*Herschel's Astronomy.*

the air is the heaviest when it contains the greatest quantity of fog and smoke, and that it is the uncommon weight of the atmosphere which presses these vapours towards the ground. A little consideration will shew, that in this case the popular belief is erroneous, for not only the barometer, but all the experiments we have detailed on the subject of specific gravity, tend to shew that the lighter any fluid is, the deeper any substance of a given weight will sink in it. Common observation ought, therefore, to correct the error, for everybody knows that a heavy body will sink in water, while a light one will swim; and by the same kind of reasoning, ought to consider, that the particles of vapour would descend through a light atmosphere, while they would be pressed up into the higher regions by a heavier air.

312. "One great use of the barometer is on board of ships, where it is employed to indicate the approach of storms, and thus to give an opportunity of preparing accordingly; and it is found that the mercury suffers a most remarkable depression before the approach of violent winds, or hurricanes. The watchful captain, particularly in southern latitudes, is always attentive to this monitor, and when he observes the mercury to sink suddenly, takes his measures without delay to meet the tempest. During a violent storm, we have seen the wheel-barometer sink a hundred degrees in a few hours. But we cannot illustrate the use of this instrument at sea, better than by giving the following extract from Dr Arnott, who was himself present at the time: 'It was,' he says, 'in a southern latitude. The sun had just set with a placid appearance, closing a beautiful afternoon, and the usual mirth of the evening watch proceeded, when the captain's orders came to prepare with all haste for a storm. The barometer had begun to fall with appalling rapidity. As yet the oldest sailors had not perceived even a threatening in the sky, and were surprised at the extent and hurry of the preparations; but the required measures were not completed, when a more awful hurricane burst upon them, than the most experienced had ever braved. Nothing could withstand it; the sails, already furled and closely bound to the yards, were riven into tatters; even the bare yards and masts were in a great measure disabled; and at one time the whole rigging had nearly fallen by the board. Such, for a few hours, was the mingled roar of the hurricane above, of the waves around, and the incessant peals of thun-

der, that no human voice could be heard, and amidst the general consternation, even the trumpet sounded in vain. On that awful night, but for a little tube of mercury, which had given the warning, neither the strength of the noble ship, nor the skill and energies of her commander, could have saved one man to tell the tale.'"

313. Allusion has been already made to the use of the barometer in measuring the height of mountains. On this subject the following anecdote, taken from Lyell's "Principles of Geology," will be read with interest:—"In 1815, Captain Smyth ascertained, trigonometrically, that the height of Etna was 10,874 feet. The Catanians, disappointed that their mountain had lost nearly 2000 feet of the height assigned to it by Recupero, refused to acquiesce in the decision. Afterwards, in 1824, Sir J. Herschel, not being aware of Captain Smyth's conclusions, determined, by careful barometrical measurement, that the height was 10,872½ feet. This singular agreement of results, so differently obtained, was spoken of by Herschel as 'a happy accident;' but Dr. Wollaston remarked that 'it was one of those accidents which would not have happened to two fools.'"

WATER PUMPS.

314. There is a philosophical experiment, of which no one is ignorant. If one end of a straw be introduced into a vessel of liquid, and the other end be sucked with the mouth, the liquid will rise through the straw, and may be swallowed. Every one is familiar with the action of the common *squirt*, or hand-syringe. This instrument consists of a cylinder, or barrel, terminating in a short suction pipe, and having its interior accurately fitted with a piston. On plunging the pipe into water, and raising the piston, the liquid rushes into the barrel by atmospheric pressure, and is then projected in a continuous stream by the descent of the piston.

315. Water pumps are machines by means of which water is elevated from various depths to the surface of the earth. There are three kinds of pump, the common suction, the lifting, and the forcing pump, so called from the manner in which they severally act.

316. *Common suction pump.*—The action of this machine depends on the principles illustrated by that of the common squirt, viz., atmospheric pressure and mechanical force. "The common pump consists of a long tube,

or barrel, called the *pump-log*, which reaches from a few feet above the ground to near the bottom of the well. At A, Fig. 127, is a valve, opening upwards, called the *pump-box*. When the pump is not in action, this is always shut. The piston B, has an aperture through it, which is closed by a valve, also opening upwards. By the pupil who has learned what has been explained under the articles air-pump, and barometer, the action of this machine will be readily understood. Suppose the piston B to be down to A, then on depressing the lever C, a vacuum would be formed between A and B, did not the water in the well rise, in consequence of the pressure of the atmosphere on that around the pump-log in the well, and take the place of the air thus removed. Then, on raising the end of the lever, the valve A closes, because the water is forced upon it, in consequence of the descent of the piston, and at the same time the valve in the piston B opens, and the water, which cannot descend, now passes above the valve B. Next, on raising the piston, by again depressing the lever, this portion of water is lifted up to B, or a little above it, while another portion rushes through the valve A to fill its place. After a few strokes of the lever, the space from the piston B to the spout, is filled with the water, where, on continuing to work the lever, it is discharged in a constant stream.

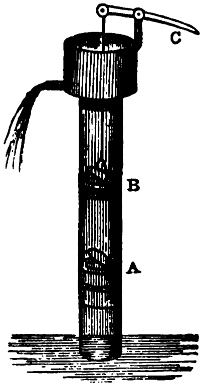


Fig. 127.

317. "Although, in common language, this is called the suction pump, still it will be observed, that the water is elevated by *suction*, or, in more philosophical terms, by atmospheric pressure, only above the valve A, after which it is raised by *lifting* up to the spout. The water, therefore, is pressed into the pump barrel by the atmosphere, and thrown out by lifting." Although, in theory, pure water may be raised, by this machine, to a height of 35¼ feet, when the mercury stands at 31 inches in the barometer, it is not found practicable, in pumps of ordinary construction, to raise it higher than about 28 feet, the difference arising from the difficulty of making the apparatus absolutely air-tight. The

several acts of respiration, suction with the mouth, drinking, smoking, &c., may all be explained by reference to the principles above announced.

318. *Lifting pump.*—In this pump, the piston is situated in the lower part of the barrel, and raises the water through the whole distance, by forcing it upward, without the agency of atmospheric pressure.

319. *Forcing pump.*—"The *forcing* pump differs from both these, in having its piston solid, or without a valve, and also in having a side pipe, through which the water is forced, instead of rising in a perpendicular direction, as in the others. The forcing pump is represented by Fig. 128, where A is a solid piston, working air-tight in its barrel. The tube, C, leads from the barrel of the air-vessel, D. Through the pipe P the water is thrown into the open air. G is a gauge, by which the pressure of the water in the air-vessel is ascertained. Through the pipe, I, the water ascends into the barrel, its upper end being furnished with a valve opening upwards.

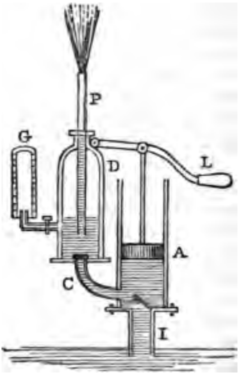


Fig. 128.

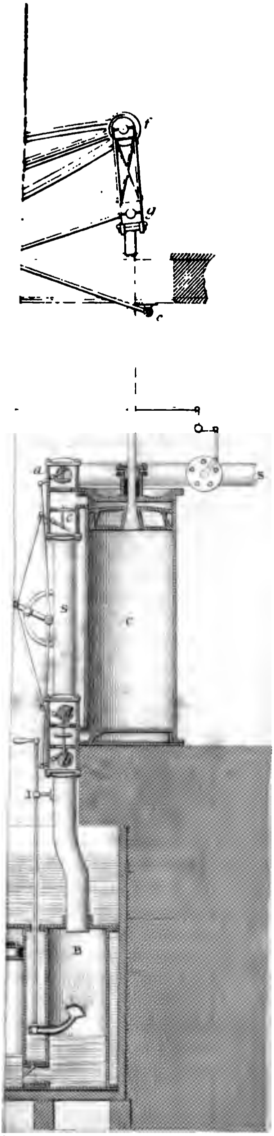
320. "To explain the action of this pump, suppose the piston to be down to the bottom of the barrel, and then to be raised upward by the lever, L, the tendency to form a vacuum in the barrel will bring the water up through the pipe, I, by the pressure of the atmosphere. Then on depressing the piston, the valve at the bottom of the barrel will be closed, and the water, not finding admittance through the pipe whence it came, will be forced through the pipe, C, and opening the valve at its upper end, will enter into the air-vessel, D, and be discharged through the pipe, P, into the open air. The water is therefore elevated to the piston barrel by the pressure of the atmosphere, and afterwards thrown out by the force of the piston. It is obvious that, by this arrangement, the height to which this fluid may be thrown, will depend on the power applied to the lever, and the strength with which the pump is made.

321. "The air-vessel, D, contains air in its upper part only,

the lower part, as we have already seen, being filled with water. The pipe, P, called the discharging pipe, passes down into the water, so that the air cannot escape. The air is therefore compressed, as the water is forced into the lower part of the vessel, and re-acting upon the fluid by its elasticity, throws it out of the pipe in a continued stream. The constant stream which is emitted from the direction-pipe of the fire engine, is entirely owing to the compression and elasticity of the air in its air-vessel. In pumps without such a vessel, as the water is forced upwards only while the piston is acting upon it, there must be an interruption of the stream while the piston is ascending, as in the common pump. The air-vessel is a remedy for this defect, and is found also to render the labour of drawing the water more easy, because the force with which the air in the vessel acts on the water, is always in addition to that given by the force of the piston."

322. In each of the pumps above described, the total effort required to work the machine, independently of friction, is equal to the weight of a column of water, the base of which is equal to the area of a section of the working barrel, and the altitude equal to the distance between the surface of the water in the reservoir and the point to which it is raised. In the suction pump, the whole of the effort is expended in raising the piston; in the forcing pump, one part is expended in raising, and the other in depressing the piston, and it is advantageous to arrange the machinery so that these two parts shall be nearly equal. In small pumps employed for domestic purposes, the strength of man is usually exerted as the moving power; but in raising water from great depths, as from the bottom of mines, the steam engine is usually employed.

323. *Chain pump.*—This kind of pump is used on board of ships, and consists of an endless chain moving over a wheel on the deck, which is turned round by winches, and over a roller in the pump-well, having saucers or flat circular pistons at certain intervals. Near the pump-well, on the side on which the chain on turning the winches ascends, are a few feet of pipe; through this the saucers raise the column of water, which, being lifted over the upper orifice of the pipe, falls into the cistern, and thence into the waste pipe, called the *pump-dale*, which carries it overboard. The descending portion of chain falls through another case, called the *back-case*. Chain pumps, in large ships, throw out a ton of water per minute.



E. Allard fc

FIRE ENGINE.

324. "The *fire engine* is a modification of the forcing pump. It consists of two such pumps, the pistons of which are moved by a lever with equal arms, the common fulcrum being at C, Fig. 129. While the piston A is descending, the other piston B, is ascending. The water is forced by the pressure of the atmosphere through the common pipe P, and then dividing, ascends into the working barrels of each piston, where the valves, on both sides, prevent its return. By the alternate depression of the pistons, it is then forced into the air-box D, and then, by the direction pipe E, is thrown where it is wanted. This machine acts precisely like the forcing pump, only that its power is doubled, by having two pistons instead of one.

325. "There is a beautiful fountain called the *fountain of Hiero*, which acts by the elasticity of the air, and on the same principle as that already described. Its construction will be understood by Fig. 130, but its form may be varied according to the dictates of fancy or taste. The boxes A and B, together with the tubes, are made air tight, and strong, in proportion to the height it is desired the fountain should play. To prepare the fountain for action, fill the box A, through the spouting tube, nearly full of water. The tube C, reaching nearly to the top of the box, will prevent the water from passing downwards, while the spouting pipe will prevent the

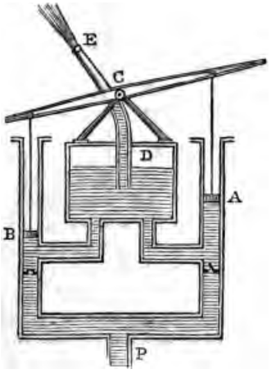


Fig. 129.

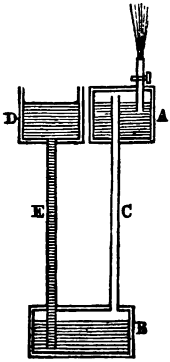


Fig. 130.

air from escaping upwards, after the vessel is about half filled with water. Next, shut the stop-cock of the spouting pipe, and pour water into the open vessel D. This will descend into the vessel B through the tube E, which nearly reaches its bottom, so that after a few inches of water are poured in, no air can escape, except by the tube C, up into the vessel A. The air will then be compressed by the weight of the column of water in the tube E, and therefore the force of the water from the jet pipe will be in proportion to the height of this tube. If this tube is 20 or 30 feet high, on turning the stop-cock, a jet of water will issue from the pipe."

THE STEAM ENGINE.

326. *Hero's machine.*—The generation of steam from water by the application of heat, and the mechanical force produced by this means, appear to have been understood at a very remote period; but their application to machinery devoted to the purposes of locomotion, is a discovery of recent date. The ingenious contrivances of early discoverers were devoted to objects of minor importance, as those of raising water, of propelling smoke upwards, &c. About 120 years before the present era, an elegant machine was constructed by Hero, of Alexandria, in which a rotatory motion was produced by means of steam. A hollow globe placed on pivots, was furnished with a pair of horizontal tubes radiating from it like the spokes of a wheel, and closed at their extremities, with the exception of a small orifice near the end, and on the side of each tube. The globe being supplied with steam, this fluid rushes through the orifices with a force equal to the excess of its elasticity over that of the atmosphere. The recoil produced by this difference of pressure, repels the tubes in the opposite direction, and a rotatory motion is produced, which may be communicated to machinery connected with the globe.

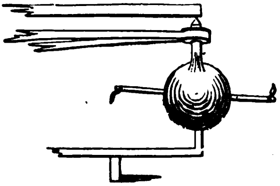


Fig. 131.

327. In 1629, Giovanni Branca, an Italian, contrived a machine which was employed for the various purposes of raising water, of sawing timber, of pounding materials, &c. His machine consisted of a wheel furnished with flat

vanes around its circumference, like the boards of a paddle-wheel. Upon these vanes, steam was propelled from a close vessel. A rotatory motion was produced, and communicated to appropriate machinery. The results, however, of these and other discoveries made about this period, have never been rendered applicable to the purposes for which the modern steam engine is adapted.

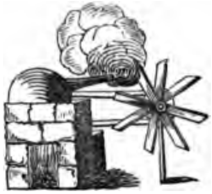


Fig. 132.

328. *Savery's steam engine.*—In 1698, Captain Thomas Savery constructed an engine, in which the force of steam is employed as a moving power for raising water. He appears to have discovered the principle of condensation by chance. Having drunk a flask of Florence wine and thrown the flask on the fire, he called for a basin of water to wash his hands. He observed that a small quantity of wine remaining in the flask began to boil, and that steam issued from the flask. He then seized the vessel, and plunging its mouth under the surface of the water in the basin, found that the liquid rushed into the flask. This experiment suggested to him the possibility of producing *a vacuum by the condensation of steam*, and bringing the atmospheric pressure to bear upon the vacuum thus produced. The adjoining figure illustrates the apparatus employed by Savery. It consists of a furnace and a boiler B; from the latter, two pipes, furnished with stopcocks C, proceed to two steam vessels S, only one of which is shown in the figure, the other being immediately behind it. Into the bottom of each of these steam vessels is inserted a branching pipe, connected with a descending main pipe D, and an ascending main pipe A; each branching pipe is furnished with valves *a*, *b*, which open upwards, and prevent, by their

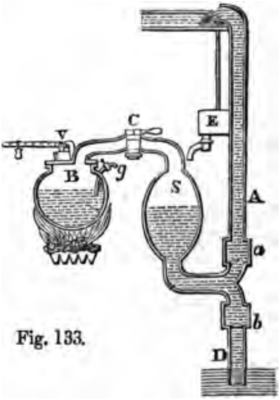


Fig. 133.

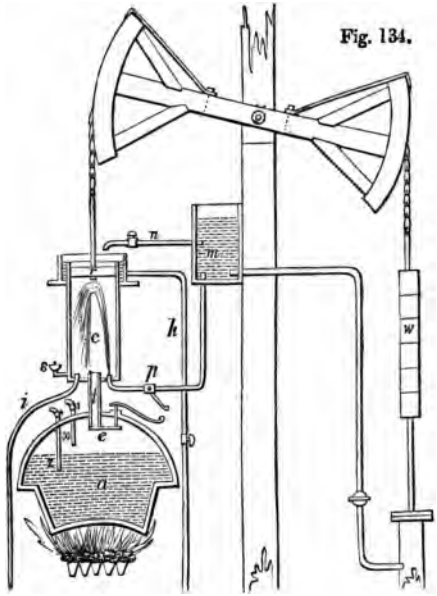
action, the return of any water which may have been forced up through them. One of the steam vessels being filled with steam, condensation is produced by projecting cold water, from a small cistern E, against the vessel; and into the partial vacuum, thus made, the water is forced up, by the pressure of the atmosphere, through the descending main pipe, from a depth of about twenty feet. The steam being then introduced again into the steam vessels, the valve *b* is closed, and the descent of the water prevented; while the steam from the boiler, pressing on the water in the steam vessel, causes it to raise the valve *a*, and ascend to a height proportional to the excess of the elastic force of the steam above the pressure of the air.

329. In this engine, accordingly, water is raised, partly by means of a vacuum produced by the condensation of steam, and partly by the elastic force of steam; the same steam which is subservient to the *forcing* effect being rendered, by its subsequent condensation, subservient to the re-production of the required *vacuum*. This engine was afterwards much simplified, one steam vessel only being employed. The risk of bursting the boiler was obviated by the use of the steelyard safety valve V. The stopcocks C, by which communication is opened with, or shut off from, the boiler, were managed by the hand, the one being opened when the other is closed. The boiler was supplied with hot water from a smaller boiler, in order to prevent loss of time in refilling it with cold water. The quantity of water in the boiler was ascertained by means of the gauge cock *g;* if steam issues from this cock, when opened, there is too little water in the boiler. Savery's engine was successful in cases in which it was required to raise water to a height of only forty feet, but was inapplicable to the important object of draining mines, owing to the vast quantity of steam wasted by condensation in a cold vessel, and by means of cold fluid, and the danger of employing steam of sufficient power to raise water to the height required.

330. *Newcomen's atmospheric engine.*—The drainage of deep mines was a matter of great importance, and the failure of Savery's engine in this respect paved the way to further experiment. In 1705, Thomas Newcomen, a smith of Dartmouth, obtained letters patent for the construction of a new kind of steam engine, in which he availed himself of the atmospheric pressure in a different way from that adopted by

Savery. The novelty of this plan consists in *the admission of steam beneath an air-tight piston, and the condensation of the steam by the injection of cold water into the interior of the cylinder*. The use of a cylinder and piston may be easily explained. In order that the pressure of steam may be rendered available in machinery, the steam must be confined within an air-tight cavity, so constructed that its dimensions, or capacity, may be altered without altering its tightness. When the steam enters such a vessel, it enlarges its actual cavity, by causing some moveable part to recede before it, and from this moveable part motion is communicated to machinery. A hollow cylinder, having a moveable piston accurately fitted to its bore, constitutes a vessel of this kind; the piston, thus employed, has an alternate or reciprocating vertical motion, which may be converted into a circular motion by appropriate machinery. The engine employed by

Fig. 134.



Newcomen, in its most improved state, was as follows:—Over a boiler *a* is fixed a cylinder *c*, containing a piston *r*, the rod of which is connected with one of the arched extremities of a lever-beam working on a pivot; to the other extremity of the beam is attached a chain connected with the pump-rod.

331. Such is the simple outline of the atmospheric engine. Its mode of operation is as follows:—Steam is admitted from the boiler into the cylinder, through the tube *l*, by means of a *regulating cock e*, which is worked by a handle outside the boiler; the pressure of the atmosphere above the piston being thus balanced by the force of the steam beneath it, the extremity of the lever-beam to which the piston is attached is elevated by proportionate weights *w* attached to the pump-rod, and the piston is drawn to the top of the cylinder, the other extremity of the beam being depressed. In order to effect the *descent* of the piston, the steam in the cylinder must now be condensed. The regulating cock *e* is accordingly closed, and the further admission of steam prevented; another cock, called the *condensing cock p*, is now opened, and a jet of cold water is admitted through a tube from the cistern *m*, which is placed at a sufficient height to ensure a forcible injection; the steam in the cylinder is instantly condensed, a vacuum is formed, and the pressure of the atmosphere forces the piston to the bottom of the cylinder, while the pump-rod on the other end of the beam is raised. Such is the general operation of Newcomen's atmospheric engine, which is merely a pump worked by steam. The subsidiary details of its operation are now to be explained.

332. The *quantity of water in the boiler* is regulated by the two *gauge cocks*, *x*, *z*, one of which, *x*, has its aperture a little above the required height of water, the other, *z*, a little below it. On opening the cocks, if the water is at its proper height in the boiler, steam will issue from the cock *x*, and water from the cock *z;* if *steam* issue from both, there is too little water in the boiler; if *water* issue from both, there is too much. This mode of regulating the height of water in the boiler was the invention of Savery, and is employed in the present day.

333. A contrivance is added for the purpose of *getting rid of the air contained in the cylinder* before the engine is in full play, and thus preventing the engine from being *air-logged.* Near the bottom of the cylinder is inserted a small

tube, opening into the atmosphere, where it is furnished with a valve, which opens upwards, and is inserted into a sort of cup *s*, containing water. The heated air and steam in the cylinder, having sufficient elastic force to overcome the atmospheric pressure, open this valve and escape with a hissing noise. This operation is called *blowing the engine*, before it starts; and the valve, from the peculiar noise attending the process, is called the *blowing* or *snifting valve*.

334. The next object is *to get rid of the injection water* and the condensed steam; for, however small the quantity might be after a few condensations, it is evident that it would quickly accumulate in the cylinder, and entirely check the movement of the piston. To carry this off, a pipe *i*, called the *eduction pipe*, is inserted into the bottom of the cylinder, and conveyed downwards into a reservoir, called the *hot-water cistern*. This pipe, as represented in the figure, must be made to descend thirty feet below the cylinder; for otherwise, being connected with a vacuum produced by the alternate motion of the piston, the atmospheric pressure would force the water to ascend from the cistern into the cylinder, instead of the water descending from the cylinder into the cistern. This difficulty is, however, easily removed by placing a valve opening downwards, called the *eduction valve*, at the outlet of the pipe *i* in the bottom of the cylinder; the cistern, in this case, may be situated close to the cylinder.

335. The *cistern m* is supplied with cold water, by a pump which branches from the main pump, and is worked by the engine. The pipe *n* admits a stream of water upon the piston, in order, by interposing a denser substance than the air, to render the piston more air-tight. The pipe *h* conducts the water, which becomes heated, from the top of the cylinder into the hot cistern below. The idea of condensing the steam by injecting water into the cylinder, appears to have been suggested by accident. At first, Newcomen enclosed his cylinder within another cylinder, and condensed the steam by filling the space between them with cold water by the pipe *n*. On the first trials of this engine, the managers were surprised to see it, without its regular supply of condensing water, "go several strokes, and very quick together; when, after a search, they found a hole in the piston, which let the *cold water in to condense the steam in the inside* of the cylinder, whereas before they had always done it on the outside." The external cylinder was, accordingly, aban-

doned, and water was henceforth injected from below, as already described. So true is it, that "the wished-for improvement is unmade, oftener because the means are overlooked, than because they are hidden from us."

336. *Watt's double-acting engine.*—In considering the applicability of the steam engine to manufactures generally, it occurred to Watt, that if he could contrive to *admit steam alternately above and below the piston, and at the same time produce a vacuum alternately below and above the piston*, an impulse might be communicated by the ascent, as well as by the descent, of the piston, and a uniform *continuous action* be thus produced. It was desirable, also, to convert this reciprocating action into a circular one. On this subject Watt observes:—"Having made my single reciprocating engines very regular in their movements, I considered how to produce *rotative motions* from them in the best manner; and amongst various schemes which were subjected to trial, or which passed through my mind, none appeared so likely to answer the purpose as the application of the *crank*, in the manner of the common turning lathe; but as the rotative motion is produced in that machine by impulse given to the crank in the descent of the foot only, it requires to be continued in its ascent by the energy of the *wheel*, which acts as a *fly*. Being unwilling to load my engine with a fly-wheel heavy enough to continue the motion during the ascent of the piston (or with a fly-wheel heavy enough to equalise the motion, even if a counter-weight were employed to act during the ascent), I proposed to employ two engines, acting upon two cranks fixed on the same axis, at an angle of 120° to one another, and a weight placed upon the circumference of the fly-wheel at the same angle to each of the cranks, by which means the motion might be rendered nearly equal, and only a very light fly-wheel would be requisite." In following out this plan, some very important changes were introduced into the machinery of the steam engine: the principal of these are the double acting cylinder, the parallel motion, the crank, the fly-wheel, and the governor. Each of these will first be severally described; and their operation in the double-acting engine be afterwards pointed out.

337. *Double-acting cylinder.*—The first alteration to be noticed in the double-acting engine is that of the cylinder. To ensure its *double action*, it is necessary to provide, at each end of the cylinder, a means of *admission* of steam from

the boiler, and of *escape* for the steam to the condenser. For this purpose, a *steam box* is fixed to each end of the cylinder, communicating in the one case with the upper, in the other with the lower, surface of the piston. In Fig. 135, B is the upper, and B' the lower, steam box. Each of these boxes is furnished with two valves. 1. In the *upper steam box*, the upper, or *steam valve*, S, admits steam from the boiler through a tube, the mouth of which is seen immediately above the valve; the lower, or *exhausting valve*, C, permits the escape of the steam from the cylinder to the condenser, through a tube opening immediately below the valve. In this figure, the piston is at the top of the cylinder; the exhausting valve is therefore represented as closed, and the steam valve as open, for the admission of steam, which rushes through the passage D to the top of the cylinder, in order to force the piston to the bottom. 2. In the *lower steam box*, a corresponding mechanism is observed, and its valves must be worked at the same moment as those of the upper box, but upon an exactly opposite principle. The cylinder is full of steam, and the piston at the top; the *steam valve* S' must therefore be closed, and the *exhausting valve* C' opened, in order that the steam may rush out at the passage D', and a vacuum be formed *beneath* the piston, to give effect to the steam which is now entering above it.

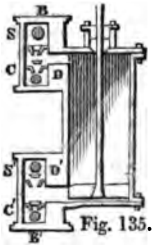


Fig. 135.

338. In Fig. 136, the piston is at the bottom of the cylinder. 1. In the *upper steam box*, the *steam valve* S is accordingly closed, and the *exhausting valve* C opened, to admit of the escape of the steam from above the cylinder through the passage D into the condenser, and thus to produce a vacuum *above* the piston. 2. In the *lower steam box*, the *exhausting valve* C' is closed, and the *steam valve* S' opened, in order that steam may rush in by the passage D', and force the piston to the top of the cylinder. From the preceding description, it is evident, that the alternate motions of the piston depend on the opening and closing of the valves, alternately, in pairs. When the piston is at the top of

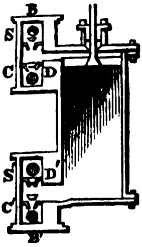


Fig. 136.

the cylinder, the upper steam valve and the lower exhausting valve are to be opened, while the lower steam valve and the upper exhausting valve are to be closed. When the piston is at the bottom of the cylinder, this process is reversed.

339. *Parallel motion.*—In the *double-acting engine*, the pressure of the steam acts on both sides of the piston, which must therefore be *pushed upward* as well as *pulled downward;* the connexion between the piston-rod and the beam by any *flexible* medium is, therefore, obviously inadmissible: a *chain* cannot communicate an *upward impulse* from the piston to the beam. The difficulty was, to adjust the *rectilinear* motion of the piston-rod to the *circular* motion of the beam; without such adjustment, it is evident that either the piston-rod, being forced to the right and left alternately, at each motion of ascent and of descent, would be broken or bent; or that the stuffing-box would be so injured by these derangements of action, as to cease to be air and steam-tight. The contrivance by which these difficulties were removed by Watt, is one of the most happy inventions ever introduced into machinery. It has been termed the *parallel motion;* its mechanism may be understood by means of the subjoined figure. B represents

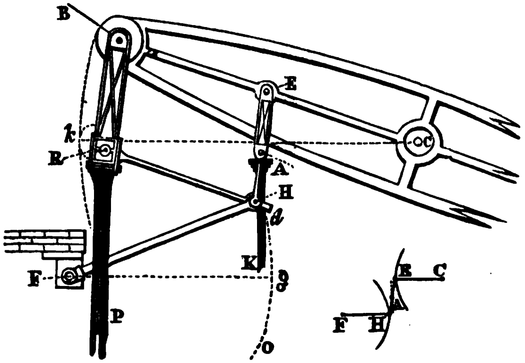


Fig. 137. Fig. 138.

the end of the beam, which is *pulled downward*, and *pushed upward*, by the motion of the piston-rod R P; the motion of B is in the direction of the dotted *curve;* that of R P is *rec-*

tilinear. To adjust these counteracting motions, a series of bars are introduced, which are moveable on pivots, and which by the balance of their action prevent the piston from deviating to any injurious extent from the straight line. *Two fixed points* of support are taken, the one at F, as near as possible to the line in which the piston-rod moves; the other at C, the centre of the working beam. *Two perpendicular bars*, B R and E H, are attached to the beam at B and E; and *two transverse bars*, R H and F H, are added, the former connecting the lower extremities of the two vertical bars, the latter connecting the lower extremity of the vertical bar E H with the fixed point F; all the bars move freely on pivots at all their points of attachment. The head of the piston-rod is connected with the pivot at R. The diagram, Fig. 138, relates to paragraph 341.

340. The *action of this machinery* is as follows. 1. Let us imagine the end of the beam B to *descend* in the direction of the dotted curve. During its progress to the *horizontal position*, indicated by the dotted line *k* C, it is continually pushing the perpendicular bar B R outward; and this effect, if not counteracted, would disturb the rectilinear course of the piston-rod. But this *outward push* of the bar B R is counteracted by an *inward pull* by the rod R H upon the point R; the end H of the rod R H is preserved at a proper distance from the line of motion of the piston-rod, by means of the rod called the *radius rod*, H F, which is attached to the fixed point F; and the rod H F, being thus fixed, describes, with its extremity H, the curve *d g*, which is directed inwardly, and counteracts the outward direction of the curve described by B. Hence it follows, that the top of the piston-rod R moves in a direction almost vertical. It is correct to say *almost*, for it is not strictly so; the deviation, however, from the vertical motion involves a minute calculation, and it is of comparatively little importance in practical operation. 2. As the beam quits the horizontal position in *completing its descent*, it is continually pushing the bar B R inward; but this *inward push* of the bar B R is now counteracted by the *outward pull* of the bar H F, which now completes the curve *g o*, and, by means of the transverse connecting bar H R, maintains the piston-rod in its nearly vertical direction. 3. It is obvious, that during the *ascent* of the beam, the same movements of the bars will secure the vertical ascent of the piston-rod. This beautiful contrivance represents, in fact, a kind of

jointed parallelogram, three of the angles of which describe curves, while the fourth, which is connected with the piston-rod, moves nearly in a straight line.

341. *Motion of the air-pump rod.*—The same machinery which regulates the motions of the piston-rod of the cylinder, also regulates those of the pump-rod. In the preceding figure 137, the upper part of the *air-pump rod* is represented at A K; it is connected at the top to the middle of the bar E H, where it works freely on a pivot A. This machinery may be readily understood by means of figure 138, in which the bars composing it are separated from the beam, the letters being preserved precisely as in figure 137. C E and F H are two bars, working on pivots at the fixed points C and F, and describing curves at their free extremities. The bar E H connects these free extremities, upon which it moves by pivots. From the antagonising action of the two transverse bars, it follows, that the point A, the head of the air-pump rod, will move in a nearly vertical direction.

342. *Nature of the crank.*—It has been shown that the alternate motions of the piston-rod, determined by the *double-acting cylinder*, are communicated to the working end of the beam, to the curved motion of which they are adjusted by the contrivance of the *parallel motion.* The next object was to convert the *rectilinear* motion, thus produced, into a *rotatory* motion. So long as the force of steam was employed for the mere purpose of raising water, no such motion was wanted; but when its application was required for the purposes of turning the wheels of mills—of giving effect to the machinery of cotton manufactures and printing presses—of propelling steam vessels and other locomotive engines—it became necessary to impart a new direction to its operation. To attain this object the crank was introduced. The simplest idea of a crank is that of the *handle to a wheel;* its action is familiarly illustrated in the process of drawing water from a well: the bent handle attached to the wheel is first pushed out, then pulled in the opposite direction, and thus a continued rotatory motion is produced upon an axle. The application of this principle to the steam engine, and the variations of pressure on the crank of a steam engine, may be conveniently illustrated by curves. This will be readily perceived in the following figure, which represents the lower portion of the connecting-rod, which works at its upper extremity on a pivot connected with the working extremity

of the beam, as may be seen more completely in the steel engraving, § 347. The lower extremity of the rod is connected by a moveable joint at I with the lever I K. The centre or axis, to which the rotatory motion is to be communicated, is indicated by the letter K. Hence it would appear, that as the connecting-rod moves upward and downward, it would carry the lever I K round the centre K, so as to occupy successively the positions denoted in the figure by the dotted shadows of the lever; and thus a continued rotatory motion would be communicated to the axis.

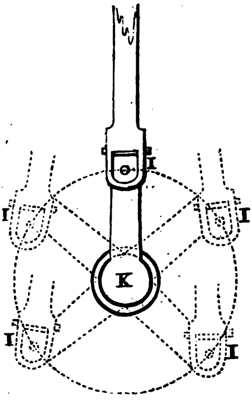


Fig. 139.

343. *Irregular action of the crank.*—On considering more closely the action of the crank, it will be found to be by no means continuous in its motion. There are *two positions* which the crank assumes in its circuit, in which the moving power has positively no effect whatever in communicating a rotatory motion to it. 1. *When the piston is at the bottom of the cylinder*, the crank will be in the position denoted in the preceding figure: the joint I will be in a perpendicular line between the upper end of the connecting-rod and the centre K. It is obvious, that as the piston ascends in the cylinder, the connecting-rod will tend to push the joint I, not to the right nor to the left of the dotted circle, but *directly downward* upon the axis K. 2. *When the piston is at the top of the cylinder*, the crank will have performed half a revolution, and the joint I will be in a perpendicular line below the centre K. As the piston descends, the connecting-rod will tend to pull the joint I, not to the right nor to the left of the dotted circle, but *directly upward* upon the axis K. It is evident, that if in either of these positions, the action of the crank were for a moment to cease, it would be out of the power of the piston to put it again into motion. 3. Another difficulty connected with the crank, is the *inequality of its motion.* In two positions, it has been shown to be actually stationary. There are also *two positions*, in

which its action is most energetic; and it becomes feebler in proportion as the crank moves from these points towards the two stationary positions above described. Let the reader once more direct his attention to the process of drawing water from a well; let him imagine his own arm to be the connecting-rod, and the handle of the wheel the crank; he will find that his force is most effective, when the angle described by his arm upon the crank is a *right angle;* and that his force will become less effective, as the angle of leverage becomes smaller or greater. The application of this simple illustration to the crank of the steam engine is obvious; and the result of it is a variable, instead of a uniform, unremitting action. In the following paragraph, a remedy for these inconveniences will be described.

344. *Nature of a fly-wheel.*—In impelling machinery by force, it is frequently necessary that *the force should be regulated.* This necessity may arise from several causes. There may be a want of uniformity in the *first moving power*, as in the single-acting engine of James Watt, in which the *descent* of the piston is effected by the pressure of steam, while its *ascent* is effected by a totally different means. Or, there may be a want of uniformity in the *resistance* which the force has to overcome, as in the *crank* described in the preceding paragraph. To regulate these inconveniences and equalise the motion, a large heavy wheel, called a *fly-wheel*, is connected with the machinery, so as to receive its motion from the impelling power, to keep up the motion by its own inertia, and distribute it *equally* in all parts of its revolution. If the moving power slackens, the fly-wheel impels the machine forward; if the power tends to impel the machine too fast, the fly-wheel slackens it. The object of the fly-wheel, therefore, is to absorb, as it were, the surplus force at one part of the action of the machine, and to give it out when the action of the machine is deficient; by Leslie it was well compared to a "reservoir which collects the intermittent currents, and sends forth a regular stream." On this subject a writer in the Penny Magazine observes, that the "fly-wheel may be considered as occupying the point of connexion between the *production* and the *consumption* of steam power. All the complex arrangements relating to the production and management of the steam have performed their wonted part when the fly-wheel is set in motion; and we may dismiss the steam engine from this point, and regard

the fly-wheel as a mighty workman, whose labours may be directed to the roughest as well as to the most delicate operations,—to the production of a cotton gown, a shilling, a Penny Magazine; a workman to whom small things cease to be small, and great things cease to be great."—*New series*, 1841.

345. *Connexion of the fly-wheel with the crank.*—In order to equalise the motion of the crank, Watt attached a *fly-wheel* to its axis, as represented in the steel engraving, § 347. This wheel is constructed of large diameter, in order that its circumference may revolve rapidly; it is of great weight, being made of lead or iron, that it may acquire considerable momentum so as to render the motion as uniform as possible; and it is so nicely placed upon the axis, as to be almost free from friction, and thus enabled to communicate its motion to the axis, when this is required from the irregular action of the crank. The objects of the fly-wheel in the steam engine, as here described, are obviously twofold: first, to extricate the machine from the mechanical difficulties which occur at the *two stationary positions* of the crank; and, secondly, to equalise the effects of the varying leverage by which the first mover acts on the crank. But besides the irregularity in the action of the crank, there are other causes which, in the absence of a fly-wheel, would disturb the uniform velocity of the engine: there are *variations of resistance*, and of *power*. The resistance which an engine has to overcome, particularly in manufactures, is continually liable to vary; it may be very great one hour, and very small the next. When the *resistance is diminished*, or the moving power increased, the excess of force is expended on the fly-wheel, to which a proportional momentum is communicated with little increase of velocity. When the *resistance is increased*, or the moving power diminished, the momentum accumulated in the fly-wheel continues the motion with little diminution of its own velocity. It is not, however, pretended that the equalisation of force produced by the fly-wheel, is perfect; but it is sufficient for ordinary purposes; and its efficiency will be proportioned to the mass of matter in the circumference of the wheel and to the square of the wheel's velocity. The next step in the progress of improvement was to regulate the velocity of the fly-wheel.

346. *Use of the governor.*—It occurred to Watt that the velocity of the fly-wheel might be regulated by *increasing*

or diminishing the supply of steam to the cylinder, as the occasion might require: if the wheel went too fast, the supply should be limited; if too slow, it should be increased. With this view, he adapted to the engine an ingenious piece of mechanism, which had been previously employed in regulating the machinery of mills, and which, from its characteristic effect, is called the *governor*. This contrivance consists in a kind of conical pendulum, connected on the one hand with the axis of the fly-wheel, and on the other with a *throttle valve* in the steam pipe. In the following figure, two balls B B are suspended at x by inflexible bars from an axis or spindle, which is made to revolve by means of a rope connected with the axis of the fly-wheel, and working in the grooved wheel G of the spindle; the velocity of the fly-wheel may therefore be estimated by that of the grooved wheel of the spindle. The two bars are prolonged from the centre x to k k, where they are connected by moveable joints with two short levers, the upper extremities of which are fixed to a moveable socket y, which slides up and down the spindle. This socket is one of the extremities of a straight lever y p, which is connected by moveable joints with two other levers, so as, entirely or partially, to open or close a valve v within the steam-pipe. If the fly-wheel move too slowly, the two balls collapse, the angles at k k become proportionably obtuse, the socket y is forced upward, the extremity p of the lever is forced downward, and the valve v is opened for the admission of more steam. On the other hand, if the fly-wheel move too rapidly, the balls fly off from the axis of the spindle, by the centrifugal force, assuming the position of the dotted balls B' B' in the figure; the angles at k k become proportionably acute, the socket y is pulled downward, the extremity of the lever p is forced upward, and the valve v is closed against the admission of steam. Such is the general principle of the Governor; different modes of combining the several parts are adopted by different engineers.

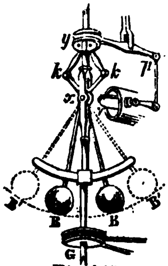


Fig. 140.

347. *Connected view of the double-acting engine.*—We are now in a condition to understand the relation which the several parts of the engine, already separately described,

bear to each other. In its general construction it resembles the single-acting engine of Watt, not described in the present work, but it differs in several important features. Among these are, its capability of performing twice the amount of work in the same time, from the simultaneous action of the pressure, and of the condensation of steam, at *each ascent and descent* of the piston; its near approximation to uniformity of power; its economy of heat, and consequently of fuel, by the diminution of cooling surface; and its reduced bulk. In the following engraving, taken from the valuable work of Tredgold, a section of this engine is illustrated; a few additional remarks to those which have already been made on its separate details, will serve to explain its general operation:

348. At the right is seen the great horizontal *steam tube* S, which admits steam into the cylinder through the *throttle valve*, which appears near S in the form of a disc. The boiler is omitted in the plate, but its connexion with the tube, and the means by which it is supplied with warm water, may be inferred from descriptions already given.

349. The *double-acting cylinder* C, its two steam boxes and four valves, and the apparatus for working the valves, are the next objects which claim attention. The piston is at the top of the cylinder. The upper steam valve A is, therefore, represented as open for the admission of steam, the upper exhausting valve C as closed; the condition of the two lower valves is reversed. The operation of opening and closing these four valves is effected by a series of levers, terminating in one handle or *spanner*, which is worked by two pegs attached to the pump-rod R. Before the piston arrives at the bottom of the cylinder, the upper peg strikes the handle of the levers downward, and in a moment reverses the condition of the four valves. The steam from above the piston then rushes down through the perpendicular tube S, issues at the lower steam valve *d*, which will now be open, and forces up the piston; but, before the piston arrives at the top of the cylinder, the lower peg strikes the handle of the levers upwards, the condition of the valves is again reversed, the steam below the cylinder rushes through the lower exhausting *b* valve into the condenser B, and the *stroke* of the engine is repeated.

350. In the *condenser* B, the steam meets with a *continual* jet of cold water. In the double-acting engine, condensa-

tion goes on equally during the descent and ascent of the piston, and the condensing jet is therefore incessantly at play. The variations which occur in the velocity of the piston, and the consequent variations in the quantity of steam discharged into the condenser, require corresponding variations in the quantity of condensing water; its amount is, therefore, regulated by the injection cock I, which is worked by a lever and handle. The water produced by condensation of the steam is removed by the *air-pump* A, and carried into the warm cistern, from which a portion of it is drawn by the pump L, and conveyed to the boiler. The cistern containing the condenser, the air-pump, and the injection cock, is supplied with water by the pump N, on the left side of the beam.

351. On the extreme left is seen the *fly-wheel* P, on the axle of which is fixed the *crank;* and this is attached by the connecting-rod O with the working extremity of the beam *h.* Behind the connecting-rod is seen the *governor;* this is connected by bevelled wheels with the fly-wheel, and it regulates, by a series of levers, one of which is seen at R, the throttle valve in the steam tube S.

352. On the right extremity of the beam is seen the apparatus which produces the *parallel motion.* The moving parallelogram is represented at *f b d g;* the rod *d c* is the *radius rod:* it terminates the arc of the circle through which the point *d* travels. At *e* is seen the extremity of the pump-rod R, which is worked by the same machinery as that of the parallel motion.

353. Returning to the left side of the beam, we find the *pumping apparatus.* D represents the barrel of the pump, and M is the pump-rod, which is connected with the beam by mechanism similar to that of the parallel motion, already described. When the piston of the pump descends, the water is forced upward through the pipe G, and conveyed by appropriate channels to a distance and height proportional to the power of the engine. The barrel of the pump is filled through the pipe F by means of machinery adapted to this purpose below; and, when the piston of the pump ascends, the valve at the left of the barrel opens, and the water rushes through in the same direction as that from the pipe G. The supply for the descent of the piston will rush in at the bottom valve from F, and be raised through the pipe G, as before. The valves with which the piston of the air-pump is furnished are termed *clacks.*

354. *High-pressure engine.*—In the preceding paragraphs the attention of the reader has been directed to the labours of Savery, Newcomen, and Watt, in perfecting a *stationary* engine for a specific purpose. There are, however, two kinds of steam engines in general use—the *high-pressure engine*, and the *low-pressure engine*. The former of these is sometimes termed the *non-condensing engine*, owing to the absence of a condensing apparatus; the steam, in this case, instead of being condensed, is discharged from the engine into the atmosphere, after having performed its task; the latter, or low-pressure engine, is also termed the *condensing engine*, from the presence of the condensing apparatus. The high-pressure engine is obviously the more simple of the two, its essential parts being only two in number, the boiler and the cylinder; whereas, the low-pressure engine requires the presence of a third part, the condenser.

355. *Leupold's high-pressure lever engine.*—A few years afterwards, an ingenious German, named Leupold, introduced the first experiment of a *high-pressure engine* worked by a cylinder and piston, and adapted to his machinery a contrivance, first indicated by Papin, of a *four-way cock.* His plan may be illustrated by the adjoined figure. Over a boiler B are placed two cylinders C C, each being provided with an air-tight piston *p*, *p;* each of the piston-rods is attached to one end of a lever working on a pivot, the other end of the lever having a pump-rod fixed to it. A four-way cock S is fixed between the boiler and the cylinders, so as alternately to admit steam into one cylinder, and permit its escape from the other. Steam of high temperature is introduced from the boiler into one of the cylinders, the piston is raised to the top of the cylinder, the pump-rod at the other end of the lever is pressed downwards, and the plunger or piston attached to it being solid, the water is raised to the required height in a force-pipe. The *four-way cock* is then turned round, and the steam escapes from this cylinder into

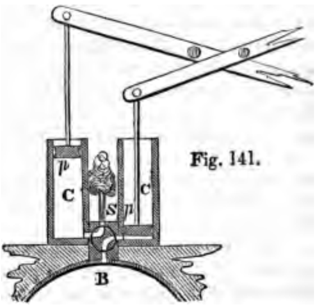


Fig. 141.

the atmosphere, while steam from the boiler is admitted into the other cylinder; the direction of the two channels from the boiler to the cylinders, is, in fact, exactly reversed, and thus, by the alternate action of the steam in the two cylinders, a continued stream of water is raised.*

ATMOSPHERIC PROPULSION.

356. *Atmospheric railway.*—The application of the atmosphere, as a locomotive power, on railroads, has become a subject of considerable interest. The discovery purports to combine the great essentials of economy, expedition, and, above all, of safety. On this plan of railroad conveyance, the moving power is communicated to the train by means of a continuous pipe or main, laid between the rails, and divided by separating valves into convenient lengths for exhaustion. A partial vacuum is formed in the pipe either by steam engines and air-pumps fixed at intervals along the road, or by water power, if the nature of the country be such as to afford it. A travelling piston, made to fit air-tight by means of a leather packing, is introduced into the main-pipe, and is connected to the leading carriage of each train by an iron plate, or coulter, which travels through a lateral opening carried through the whole length of the pipe. The lateral opening is covered by a valve, extending the whole length, and formed of a strip of leather riveted between iron plates. On exposing the front of the piston to the exhausted portion of the pipe, the atmospheric air, pressing on its back, propels it forward into the pipe, and, with it, the train to which it is attached.

357. On this subject, Mr Samuda offers the following remarks:—"A main pipe, 18 inches diameter, will contain a piston of 254 inches area: the usual pressure on this piston, produced by exhausting the pipe, should be 8 lbs. per square inch (as this is the most economical degree of vacuum to work at, and a large margin is left for obtaining higher vacuums to draw trains heavier than usual on emergencies)—a tractive force of 2032 pounds is thus obtained, which will draw a train weighing 45 tons, at 30 miles per hour, up an incline rising 1 in 100. Two and a half miles of this pipe will contain 23,324

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* The limits of the present work do not admit of further details of this interesting subject. For a full account of the history and machinery of the *locomotive* engine, as at present employed on railroads, the reader is referred to Hoblyn's *Manual of the Steam Engine.*

cubic feet of air, $\frac{16}{30}$ths of which, or 12,439 cubic feet must be pumped out to effect a vacuum equal to 8lbs. per square inch; the air-pump for this purpose should be 5 feet 7 inches diameter, or 24·7 feet area, and its piston should move through 220 feet per minute, thus discharging at the rate of $24{\cdot}7 \times 220 = 5434$ cubic feet per minute at first, and at the rate of 2536 cubic feet per minute when the vacuum has advanced to 16 inches mercury, or 8lbs. per square inch, the mean quantity discharged being thus 3985 feet per minute: therefore $\frac{12439}{3985} = 3{\cdot}1$ minutes, the time required to exhaust the pipe; and as the area of the pump-piston is 14 times as great as that in the pipe, so the velocity of the latter will be 14 times as great as that of the former, or 220 feet per minute $\times 14 = 3080$ feet per minute, or 35 miles per hour: but in consequence of the imperfect action of an air-pump, slight leakages, &c., this velocity will be reduced to 30 miles per hour, and the time requisite to make the vacuum increased to 4 minutes: the train will thus move over the 2½ miles section in 5 minutes, and it can be prepared for the next train in 4 minutes more, together 9 minutes; 15 minutes is therefore ample time to allow between each train, and supposing the working day to consist of 14 hours, 56 trains can be started in each direction, or 2520 tons, making a total of 5000 tons per day. The fixed engine to perform this duty will be 110 horses' power, equivalent to 22 horses' power per mile in each direction."

358. The rate of travelling by the atmospheric railway will depend on the rate at which the air in front of the piston may continue to be pumped out by the engine, a sufficient degree of exhaustion having been previously obtained to move the load at the required velocity. There appears to be no reason to doubt that a speed of sixty miles per hour may be easily, economically, and safely obtained by this mode of locomotion.

QUESTIONS ON CHAP. VI.

275. What is Pneumatics? What is air? What is gas? What is meant when it is said that a vessel is filled with air? Is there any difficulty in expelling the air from vessels?—276. What is meant by the elasticity of air? How does air differ from steam and some of the gases in respect to its elasticity? Does air lose its elastic force by being long compressed?—277. In what proportion to the force employed is the bulk of air lessened?—278. In what proportion will a quantity of air increase in bulk, as the pressure is removed from it? How is this illustrated by Fig. 117? On what circumstance, therefore, will the bulk of a given portion of air depend?—279. How is it proved that air has weight?—280. Explain in what manner the pressure of the atmosphere is shown by Fig. 118. What is the force pressing on the piston, when drawn upward, sometimes called?—281. How may the pressure of the atmosphere on the surface of a man be estimated?—282. How is it proved that it is the weight of the atmosphere, instead of suction, which makes the piston rise with difficulty?—283. What is the pressure of the atmosphere on every square inch of surface on the earth? What is the number of square inches in a circle of one foot in diameter? What is the weight of the atmosphere on a surface of a foot in diameter?

284. What is the air-pump? What is the receiver of an air-pump? What is a vacuum? Explain the construction of the air-pump, with reference to Fig. 119.—285. Explain the operation of the air-pump. What is the limit to the exhausting power of the air-pump, as above described? Is the air-pump capable of producing a perfect vacuum?—286. Describe Mr Chalmers's modification of the air-pump? For what purpose was it contrived?—287. Why have common air-pumps more than one barrel and piston? How are the pistons of an air-pump worked?—288. While the piston A is ascending, which valves will be open, and which closed? When the piston A descends, what becomes of the air with which its barrel was filled? Why does not the air pass from one barrel to the other through the valves *m* and *n*?—289. Enumerate some experiments which may be performed by means of the air-pump, and which illustrate the expansibility and pressure of the atmosphere.

290. How does the condenser operate?—291. Explain Fig. 122, and show in what manner the air is condensed.—292. Explain the principle of the air-gun.

293. Of what ingredients does atmospheric air consist? In what proportions do these ingredients exist? Show the beneficial result of such a constitution of the air. From what sources is watery vapour acquired by the air? What forms does it assume?—294. How may it be shewn that carbonic acid exists in the air? What is the *mean* proportion in which this gas occurs in the atmosphere? What variations in quantity does it undergo? At what times, and under what circumstances, is it more abundant? What is its relation to vegetable life? From what sources is it generated?—295. What is the weight of atmospheric air? How is its bulk influenced? What is the relation between its volume and the pressure to which it is subjected?—296. How does the temperature of the atmosphere vary? In what proportion does the temperature vary, with reference to elevation from the earth's surface? Explain the two causes of this phenomenon.

297. Suppose the tube, Fig. 123, to stand with its lower end in the water, and the piston B to be drawn upward thirty-five feet, how far will the water follow the piston? What will remain in the tube between the piston and the water, after the piston rises higher than thirty-three feet? What is commonly supposed to make the water rise in such cases? Is there any reason why the suction should cease at 33 feet?—298. What is the true cause of the elevation of the water, when the piston, Fig. 123, is drawn up? How is it shewn by Fig. 124, that it is the pressure of the atmosphere which causes the water to rise in the pump-barrel?—299. Suppose the ice prevents the atmosphere from pressing on the water in a vessel, can the water be pumped out?—300. What conclusion follows from the experiments above described? How is it proved that the pressure of the atmosphere is equal to the weight of a column of water 33 feet high? How do experiments on other fluids show that the pressure of the atmosphere is equal to the weight of a column of water 33 feet high?—301. How high does mercury rise in an exhausted tube?

302. What is the principle on which the barometer is constructed? What does the barometer measure? Describe the construction of the barometer, as represented by Fig. 125.—303. How is the vessel of the portable barometer made, so as to retain the mercury, and still allow the air to press upon it? What is the use of the metallic plate and screw, under the bottom of the vessel?—304. Explain the reason why the mercury does not fall out of the barometer tube, when its open end is downwards. —306. What fills the space above 29 inches in the barometer

tube? In the common barometer, how is the rise and fall of the mercury indicated?—307. Why was the wheel barometer invented? Explain Fig. 126, and describe the construction of the wheel barometer.—308. What is stated to be the medium range of the barometer at the surface of the earth? Suppose the instrument is elevated from the earth, what is the effect on the mercury? How does the barometer indicate the heights of mountains? What is the medium range of the mercury on Mont Blanc?—309. What is stated to be the medium range of the barometer at Cambridge in Massachusetts?—310. How many inches does a fixed barometer vary in height?—311. When the mercury falls, what kind of weather is indicated? When the mercury rises, what kind of weather may be expected? When fog and smoke descend towards the ground, is it a sign of a light or heavy atmosphere? By what analogy is it shewn that the air is lightest when filled with vapour?—312. Of what use is the barometer on board of ships? When does the mercury suffer the most remarkable depression? What remarkable instance is stated where a ship seemed to be saved by the use of the barometer?

314. What illustrations are given of the action of the common pump?—315. How many kinds of pump are described?—316. On what does the action of the common pump depend? Which kind is the common? Describe the common pump. Explain how the common pump acts. When the lever is depressed, what takes place in the pump barrel? When the lever is elevated, what takes place?—317. How far is the water raised by atmospheric pressure, and how far by lifting? To what height may water be raised, by means of the common pump? Why is this height never actually attained? What other acts may be explained by reference to the above principles?—318. How does the lifting pump differ from the common suction pump?—319. How does the forcing pump differ from the common pump?—320. Explain Fig. 128, and shew in what manner the water is brought up through the pipe, I, and afterwards thrown out at the pipe, P.—321. Why does not the air escape from the air-vessel in this pump? What effect does the air-vessel have on the stream discharged? Why does the air-vessel render the labour of raising the water more easy?—322. In the several pumps now described, to what is the effort required to work them, proportioned?—323. What is the construction of the chain pump? What is its effect per minute?

324. Explain Fig. 129, and describe the action of the fire engine. What causes the continued stream from the direction

pipe of this engine?—325. How is the fountain of Hiero constructed? On what will the height of the jet from Hiero's fountain depend?

326. Explain the principle of Hero's machine.—327. What was Branca's engine?—328. How did Savery discover the possibility of producing a vacuum by the condensation of steam? Describe his engine.—329. Explain its mode of action by reference to Fig. 133. In what respect was Savery's engine deficient?—330. What is the principle of Newcomen's engine?—331. Explain its operation, by reference to Fig. 134.—332. How is the quantity of water in the boiler regulated?—333. How is the air contained in the cylinder discharged?—334. How is the injection water got rid of?—335. How is the cistern supplied with water?

336. What improvement first suggested itself to Watt?—337. Explain the action of the double-acting cylinder.—339. What difficulty suggested the machinery of the parallel motion? Explain this machinery with reference to Fig. 137.—340. Describe its action.—341. How is the motion of the air-pump rod regulated?—342. What is a crank? Explain Fig. 139.—343. Explain the irregularity of its action. Which are the dead points of the crank?—344. How are the irregularities of the crank equalised? What is a fly-wheel? How does it operate?—345. How is the fly-wheel connected with the crank? What are its two objects?—346. How is the velocity of the fly-wheel regulated? Explain the machinery and action of the governor.—347. What is the general character of Watt's double-acting engine?—348. How is the steam admitted into the cylinder? See folding plate.—349. Explain the action of the steam valves.—350. What is the use of the condenser? How is the water, produced by condensation, discharged?—351. Point out the fly-wheel, crank, governor, parallel motion, and pumping apparatus, as described in this and the two following paragraphs.

354. What is the difference between a high-pressure and a low-pressure engine? By what other names are they respectively designated? Which is the more simple of the two, and why?—355. Describe Leupold's high-pressure engine.

356. In the atmospheric railway, how is the moving power communicated to the train? How is the vacuum formed? Explain the action of the piston.—357. What is the tractive force obtained by a main pipe of 18 inches diameter, with a pressure of 8 lbs. per square inch on the piston? How many tons per day may be conveyed by this mode of locomotion?—358. On what does the rate of travelling by atmospheric pressure depend?

CHAP. VII.

OF ACOUSTICS.

359. *Undulations.*—The constituent particles of all bodies are usually held, by the operation of certain internal and external forces, in a state of equilibrium; and, when these particles have been to a certain extent disturbed by any cause, they return to the state of equilibrium, by alternately approaching the position of rest and receding from it, until by a gradually decreasing recession, they attain the condition of repose. These movements are called *undulations*, *vibrations*, or *oscillations*.

1. Vibration may take place in all *solid* bodies which possess a requisite degree of elasticity. The elastic force, necessary for vibration, may either be an innate property of the mass, as in rods and plates of metal, and glass; or it may be acquired by means of tension, as in cords and membranes. Bodies of a *linear* form are capable of exhibiting three kinds of vibration, the transverse, the longitudinal, and the rotatory. 1. If a piece of whip cord be strained tight and firmly held at each end, and be then pulled in the middle from its position of rest, and suddenly let go, it undergoes a series of *transverse* vibrations. 2. If the cord be held at one end, and a weight attached to the other end be raised, and then let go, a series of *longitudinal* vibrations is produced. 3. Lastly, if the cord be twisted by means of the weight, and the weight be suddenly allowed to fall, the cord exhibits a series of *rotatory* vibrations. To the subject of vibration of solid bodies we shall presently have occasion to return.
2. Undulation is produced in non-elastic, or *liquid* bodies, as water, either by dropping a solid body into the liquid, or by withdrawing an immersed solid from the liquid. Around the point of impression a circular elevation is formed on the surface of the water, and immediately adjoining it is a corresponding depression; these constitute a *circular undulation.* The wave, thus produced, traverses the surface of the water, and a series of concentric circles is formed, each of which becomes progressively larger, as it travels further from the point of impression. These alternate elevations and depressions,

gradually decrease in height and depth, until at length the equilibrium is restored.

3. Undulation occurs in elastic, or *fluid* bodies, as atmospheric air, by any cause which disturbs their equilibrium. If an impulse of any kind be imparted to the air at any point, it will be communicated to the surrounding contiguous particles, in all directions with equal velocity. A *sphere of air* is thus formed around the point of impulse, the expansion of which is gradually arrested by the reaction of the condensed air, until, at last, the sphere contracts, and the air recovers its former equilibrium.

360. By the term ACOUSTICS is denoted that branch of natural philosophy, which treats of the origin, propagation, and effects of sound. When a sonorous or sounding body is struck, it is thrown into a tremulous or vibrating motion. This motion is communicated to the surrounding air, and is conveyed by this medium to the drum of the ear, which also undergoes a vibratory motion, and this last motion, by throwing the auditory nerves into action, produces the sensation of *hearing*. The phenomena of sound have in many particulars a strong analogy to those of light. Hooke and Euler supposed both to consist in a mere vibration, or impulse of ether, or air. Newton contended for a peculiar luminous fluid, or matter of light, distinct from ether; and Epicurus for a peculiar sonorous fluid, or matter of sound, distinct from air; an opinion which Lamarck appears to have revived in our own times.

361. "If any sounding body of considerable size is suspended in the air, and struck, this tremulous motion is distinctly visible to the eye, and while the eye perceives its motion, the ear perceives the sound. That sound is conveyed to the ear by the motion which the sounding body communicates to the air, is proved by an interesting experiment with the air-pump. Among philosophical instruments, there is a small bell, the hammer of which is moved by a spring connected with clock-work, and which is made expressly for this experiment. If this instrument be wound up, and placed under the receiver of an air-pump, the sound of the bell may at first be heard to a considerable distance, but as the air is exhausted, it becomes less and less audible, until no longer to be heard, the strokes of the hammer, though seen by the eye, producing no effect upon the ear. Upon allowing the

air to return gradually, a faint sound is at first heard, which becomes louder and louder, until as much air is admitted as was withdrawn.

362. "On the contrary, when the air is more dense than ordinary, or when a greater quantity is contained in a vessel, than in the same space in the open air, the effect of sound on the ear is increased. This is illustrated by the use of the diving-bell. When this machine is sunk to any considerable depth, the water above, by its pressure, condenses the air under it with great force. In this situation, a whisper is as loud as a common voice in the open air, and an ordinary voice becomes painful to the ear. Again, on the tops of high mountains, where the pressure or density of the air is much less than on the surface of the earth, the report of a pistol is heard only a few rods, and the human voice is so weak as to be inaudible at ordinary distances. Thus, the atmosphere which surrounds us is the medium by which sounds are conveyed to our ears, and to its vibrations we are indebted for the sense of hearing, as well as for the pleasure derived from the sounds of music.

363. "The atmosphere, though the most common, is not, however, the only, or the best conductor of sound. Solid bodies conduct sound better than elastic fluids. Hence, if a person apply his ear to a long stick of timber, the scratch of a pin may be heard from the other end, which could not be perceived through the air. The earth conducts loud rumbling sounds made below its surface to great distances. Thus, it is said, that in countries where volcanoes exist, the rumbling noise which generally precedes an eruption, is heard first by the beasts of the field, because their ears are commonly near the ground, and that by their agitation and alarm, they give warning of its approach to the inhabitants. The American Indians discover the approach of horses or men, by laying their ears on the ground, when they are at such distances as not to be heard in any other manner."

364. The rate of velocity, at which sound is propagated through the air, has been variously estimated. When a gun is fired at a considerable distance, the flash is seen a certain time before the report is heard; and the same phenomenon is observed with respect to the stroke of a hammer, the fall of a stone, or any visible action, which produces a sound. The method generally adopted for ascertaining the velocity of sound, is, to measure, by means of a stop watch or pen-

dulum, the time which elapses between the appearance of the flash, and the hearing of the report of a gun fired at a certain measured distance from the observer; for light travels so fast through a distance of 1000 or 2000 miles, that we cannot possibly appreciate the time; we may, therefore, conclude that the explosion of a gun takes place at the very moment in which the flash is perceived. Now, it has been invariably noticed, that sound travels at a uniform rate: thus, it will travel twice as far in two seconds, as it will in one second; and it will travel three times as far in three seconds, as it will in one, and so on. Therefore, in this manner of estimating the velocity of sound, if the distance, in feet, between the gun and the observer, be divided by the number of seconds which elapse between the perception of the flash and of the report, the quotient will show the rate of travelling, or how many feet per second are traversed by the sound.

365. The experiments and calculations of Derham, Flamstead, and Halley, lead to the general conclusion that sound travels uniformly through the atmosphere at the rate of 1142 feet per second, or one mile in little less than five seconds; at least, this result cannot differ from the truth by more than fifteen or twenty feet. The difficulty, however, of measuring time to a fraction of a second, is too great to admit of absolute accuracy. 1. Derham observed, that the report of a cannon fired at a distance of thirteen miles, did not strike on his ear as a single sound, but was repeated five or six times close to each other. 'The first two cracks,' he says, 'were louder than the third, but the last cracks were louder than any of the rest. And, besides, in some of my stations, besides the multiplied sound, I plainly heard a faint echo, which was reflected by my church, and the houses adjacent.' 2. This repetition of the sound was probably caused by reflection of a single sound from hills, houses, or other objects, not very distant from the cannon. But it appears from general observation, and where no echo can be suspected, that the sound of a cannon, at a distance of ten or twenty miles, differs from a sound proceeding from an object which is near. In the latter case, the crack is loud and instantaneous, and we are unable to appreciate its height; whereas, in the former case, it is a grave sound, which may be compared with a determinate musical sound, and, instead of being instantaneous, it begins softly, swells to its extreme loudness, and then dies away Nearly the same thing may be observed with respect

to a clap of thunder. Other sounds are likewise altered in quality by the distance through which they are propagated. 3. In estimating the velocity of sound, the state of the atmosphere, with regard to wind, must be taken into consideration. But the velocity of the air in the strongest wind is, perhaps, not equal to the twentieth part of the velocity of sound. 4. A slight alteration in the velocity of sound is occasioned by difference of temperature; the propagation of sound is rather quicker in summer than in winter. 5. Different altitudes of the barometer, as also different quantities of moisture in the atmosphere, occasion slight variations in the velocity of sound, but these variations cannot be determined with reference to these causes respectively.

366. Upon the whole it appears, that whatever increases the elasticity of the air, accelerates the motion, as also the intensity, of sound through this medium, and *vice versâ*. Or, in fluids of a determinate elasticity, whatever increases the density, diminishes the velocity of sound through them. Probably the velocities of sound through such fluids, are as the squares of the densities. Experience seems to prove, that at different seasons of the year, the influence of the winds being excluded, the velocity of sound may be faster or slower, not exceeding thirty feet, than at the above-mentioned mean rate of 1142 feet per second.

367. The knowledge of the velocity of sound through the air may be applied to the measurement of distances. The distance of a thunder cloud, for instance, may be estimated by measuring the time which elapses between the appearance of the flash of lightning and the report of the explosion or thunder; for if, by looking on a watch with a second's hand, we find the interval to be one second, we may conclude that the explosion took place at the distance of 1142 feet from us; if the interval be two, three, or any other number of seconds, we may conclude that the distance is the product of 1142, multiplied by the number of seconds. In the same manner, by observing the flash and the report of a gun, or the motion of the hand which moves a hammer, and the perception of the sound, we may determine, approximately, the distance of a ship, of an island, of a workman, &c.

368. "Solid substances convey sounds with greater velocity than air, as is proved by the following experiment, lately made at Paris, by M. Biot. At the extremity of a cylindrical tube, upwards of 3000 feet long, a ring of metal was placed.

of the same diameter as the aperture of the tube; and in the centre of this ring, in the mouth of the tube, was suspended a clock bell and hammer. The hammer was made to strike the ring and the bell at the same instant, so that the sound of the ring would be transmitted to the remote end of the tube, through the conducting power of the tube itself, while the sound of the bell would be transmitted through the medium of the air inclosed in the tube. The ear being then placed at the remote end of the tube, the sound of the ring, transmitted by the metal of the tube, was first heard distinctly, and after a short interval had elapsed, the sound of the bell, transmitted by the air in the tube, was heard. The result of several experiments was, that the metal conducted the sound at the rate of about 11,865 feet per second, which is about ten and a half times the velocity with which it is conducted by the air."

369. The following are the results of Chladni's experiments, as stated by himself:—"Articulated tones are also conducted exceedingly well through hard bodies, as I found by experiments which I made with some of my friends. Two persons who stopped their ears could converse with each other, when they held a long stick, or a series of sticks, between their teeth, or rested their teeth against them. It is all the same whether the person who speaks rests the stick against his throat or his breast, or whether one rests the stick, which he holds in his teeth, against some vessel into which the other speaks. The effect will be greater, the more the vessel is capable of a tremulous movement. It appeared to be strongest with glass and porcelain vessels; with copper kettles, wooden boxes, and earthen pots, it was weaker. Sticks of glass, and next fir-wood, conducted the sound best. The sound could also be heard when a thread was held between the teeth by both, so as to be somewhat stretched. Through each substance, the sound was modified in a manner a little different. By resting a stick, or other body, against the temples, the forehead, and the external cartilaginous part of the ear, sound is conveyed to the interior organs of hearing; as will readily appear, if you will hold your watch to those parts of another person who has stopped up his ears. From this it appears, as well as from the experiments relative to the hearing under water, that hearing is nothing else than, by means of the organs of hearing, to be sensible of the tremulous movement of an

elastic body, whether this tremulous movement be conveyed through the air, or any other fluid or hard body, to the auricular nerves. It is also essentially the same, whether, as is usually the case, the sound be conveyed through the internal part of the ear, or whether it be communicated through any other part of the body. It certainly would be worth the trouble to make experiments, to try whether it might not be possible that deaf and dumb people, when the deficiency lies only in the external organs of the ear, the auricular nerve being perfect, could not, by the above method of conducting sound, be made to hear distinctly words articulated, as well as other sounds."

370. *Echo.*—"Sound moves forward in straight lines, and in this respect follows the same laws as moving bodies, and light. It also follows the same laws in being reflected, or thrown back, when it strikes a solid, or reflecting surface. If the surface be smooth, and of considerable dimensions, the sound will be reflected, and an *echo* will be heard; but if the surface be very irregular, soft, or small, no such effect will be produced. In order to hear the echo, the ear must be placed in a certain direction, in respect to the point where the sound is produced, and the reflecting surface. If a sound be produced at A, Fig. 142, and strike the plain surface B, it will be reflected back in the same line, and the echo will be heard at C or A: that is, the angle under which it approaches the reflecting surface, and that under which it leaves it, will be equal.

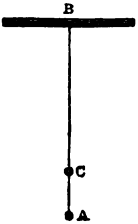

Fig. 142.

371. "Whether the sound strike the reflecting surface at right angles or obliquely, the angle of approach, and the angle of reflection, will always be the same, and equal. This is illustrated by Fig. 143, where suppose a pistol to be fired at A, while the reflecting surface is at C; then the echo will be heard at B, the angles 2 and 1 being equal to each other.

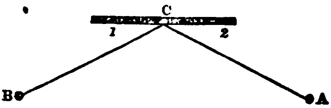

Fig. 143.

372. "If a sound be emitted between two reflecting surfaces, parallel to each other, it will reverberate, or be answered

backwards and forwards several times. Thus if the sound be made at A, Fig. 144, it will not only rebound back again to A, but will also be reflected from the points C and D; and were such reflecting surfaces placed at every point around a circle from A, the sound would be thrown back from them all, at the same instant, and would meet again at the point A. We shall see, under the article Optics, that light observes exactly the same law in respect to its reflection from plane surfaces, and that the angle at which it strikes, is called the *angle of incidence*, and that under which it leaves the reflecting surface is called the *angle of reflection*. The same terms are employed in respect to sound.

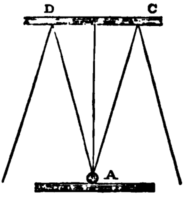

Fig. 144.

373. "In a circle, as mentioned above, sound is reflected from every plane surface placed around it, and hence, if the sound is emitted from the centre of a circle, this centre will be the point at which the echo will be most distinct. Suppose the ear to be placed at the point A, Fig. 145, in the centre of a circle; and let a sound be produced at the same point, then it will move along the line A E, and be reflected from the plane surface back on the same line to A; and this will take place from all the plane surfaces placed around the circumference of a circle; and, as all these surfaces are at the same distance from the centre, so the reflected sound will arrive at the point A at the same instant; and the echo will be loud, in proportion to the number and perfection of these reflecting surfaces. It is apparent that the auditor, in this case, must be placed in the centre from which the sound proceeds, to receive the greatest effect.

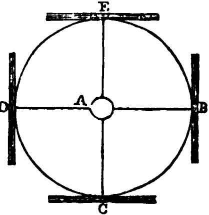

Fig. 145.

374. "But if the shape of the room be oval, or elliptical, the sound may be made in one part, and the echo will be heard in another part, because the ellipse has two points, called *foci*, at one of which the sound being produced, it will be concentrated in the other. Suppose a sound to be produced at A, Fig. 146, it will be reflected from the sides of the room, the angles of incidence being equal to those of re-

flection, and will be concentrated at B. Hence a hearer standing at B, will be affected by the united rays of sound from different parts of the room, so that a whisper at A will become audible at B, when it would not be heard in any other part of the room. Were the sides of the room lined with a polished metal, the rays of light or heat would be concentrated in the same manner. The reason of this will be understood, when we consider, that an ear, placed at C, will receive only one ray of the sound proceeding from A, while if placed at B, it will receive the rays from all parts of the room. Such a room, whether constructed by design or accident, would be a *whispering gallery.*"

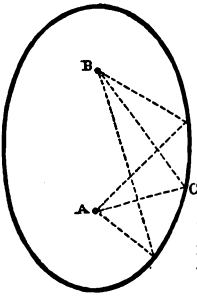

Fig. 146.

375. Several reflecting surfaces may be so situated, in respect to distance and direction, that a sound, proceeding from a certain point, will be reflected first by one surface, then by another at a little distance, afterwards by a third, and so on; or it will be reflected from the first surface to the second, from the second to the third, and so on. Hence a sound may be repeated several times.

376. According to the distance at which the speaker stands, a reflecting object will return an echo of several, or of fewer syllables; for, in order to avoid confusion, all the syllables must be uttered before the echo of the first syllable reaches the ear. In a moderate way of speaking, about 3½ syllables are pronounced in one second, or seven syllables in two seconds. Therefore, when an echo repeats seven syllables, the reflecting object is 1142 feet distant; for sound travels at the rate of 1142 feet per second, and the distance from the speaker to the reflecting object, and again from the latter to the former, is twice 1142 feet. When the echo returns fourteen syllables, the reflecting object must be 2284 feet distant, and so on. It is stated that a famous echo in Woodstock park repeats seventeen syllables in the day, and twenty at night. On the north side of Shipley church, in Sussex, it is said that an echo repeats distinctly, under favourable circumstances, twenty-one syllables.

377. "On a smooth surface, the rays, or pulses of sound will pass with less impediment than on a rough one. For

this reason, persons can talk to each other on the opposite sides of a river, when they could not be understood to the same distance over the land. The report of a cannon, at sea, when the water is smooth, may be heard at a great distance, but if the sea is rough, even without wind, the sound will be broken, and will reach only half as far." In favourable circumstances, the striking of the clock on the bell of St Paul's Church, in London, has been heard at Windsor. It has been said that, with a particular concurrence of favourable circumstances, the human voice has been heard at the distance of more than ten miles, viz., from Old Gibraltar to New Gibraltar.* The discharge of an ordinary musket can hardly ever be heard further than seven or eight miles; but the discharge of several such muskets at the same time may be heard from a greater distance. The quick repetition of the same sound may also be heard somewhat further than the same singly. In the Dutch war of the year 1672, it has been said, that the reports of the cannons were heard at the distance of 200 miles, and upwards.

MUSICAL SOUNDS.

378. "The *strings* of *musical instruments* are elastic cords, which being fixed at each end, produce sounds by their vibrations. The string of a *violin* or *pianoforte*, when pulled to one side by its middle, and let go, vibrates backwards and forwards like a pendulum, and striking rapidly against the air, produces tones, which are grave or acute according to its tension, size, or length. The manner in which such a string vibrates is shown by Fig. 147.

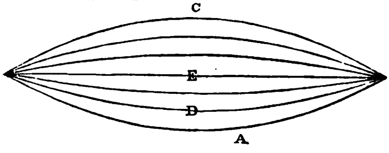

Fig. 147.

If pulled from E to A, it will not stop again at E, but in passing from A to E, it will gain a momentum, which will carry it to C, and in returning, its momentum will again carry it to D, and so on, backwards and forwards, like a pendulum, until its tension, and the resistance of the air, finally bring it to rest.

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* Derham's Physico-Theology, B. iv. chap. 3. See also the Phil. Trans. No. 300, for more facts of this nature.

379. "The *grave* or *sharp* tones of the same string depend on its different degrees of tension; hence, if a string be struck, and while vibrating, its tension be increased, its tone will be changed from a lower to a higher pitch. Strings of the same length are made to vibrate slow or quick, and consequently to produce a variety of sounds, by making some larger than others, and giving them different degrees of tension. The *violin* and *bass viol* are familiar examples of this. The low, or bass strings, are covered with metallic wire, in order to make their magnitude and weight prevent their vibrations from being too rapid, and thus they are made to give deep or grave tones. The other strings are diminished in thickness, and increased in tension, so as to make them produce a greater number of vibrations in a given time, and thus their tones become sharp or acute in proportion.

380. "Under certain circumstances, a long string will divide itself into halves, thirds, or quarters, without depressing any part of it, and thus give several harmonious tones at the same time. The fairy tones of the *Æolian harp* are produced in this manner. This instrument consists of a simple box of wood, with four or five strings, two or three feet long, fastened at each end. These are tuned in unison, so that when made to vibrate with force, they produce the same tones. But when suspended in a gentle breeze, each string, according to the manner or force in which it receives the blast, either sounds as a whole, or is divided into several parts, as above described. 'The result of which,' says Dr Arnott, 'is the production of the most pleasing combination and succession of sounds that the ear ever listened to, or fancy perhaps conceived. After a pause, this fairy harp is often heard beginning with a low and solemn note, like the bass of distant music in the sky; the sound then swells as if approaching, and other tones break forth, mingling with the first and with each other.'

381. "The manner in which a string vibrates in parts will be understood by Fig. 148. Suppose the whole length of the

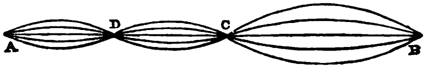


Fig. 148.

string to be from A to B, and that it is fixed at these two points. The portion from B to C vibrates as though it were fixed at C, and its tone differs from those of the other parts of the string. The same happens from C to D, and from D to A. While a string is thus vibrating, if a small piece of paper be laid on the part C or D, it will remain, but if placed on any other part of the string, it will be shaken off."

382. When the vibrations of a string succeed each other with such regularity as to produce the impression of a single sound, this is called a *musical sound.* Musical sounds differ from each other, partly in regard to quantity, partly in quality. 1. The *quantity* of a musical sound depends on the extent and velocity of the vibrations, and therefore corresponds to the *strength* or *intensity* of the sound. Thus, the further a string is drawn from its position of rest, the louder will be its sound; the more violently a bell is shaken, the louder will it ring. Musical sounds are termed *notes*, and are distinguished as *high* and *low*, with reference to the number of vibrations: if two notes be sounded at the same time, that which is produced by the greater number of vibrations, is called the higher note; thus, if a cord, while vibrating through its entire length, be suddenly shortened, its vibrations will be more rapid, and the note will be raised. 2. The *quality* of a sound relates to the different bodies by which it is produced. If two notes of similar intensity be produced, the one by the human voice, the other by a tense string or by a bird, the quality of each is readily appreciated by the ear, though no account can be given of the different emotions occasioned by them.

383. The capacity of the human ear for appreciating the vibrations of a sonorous body is restricted within certain limits. It has been proved by experiment, that the lowest note we are capable of perceiving is that produced by a body performing 32 half-vibrations, or 16 impulses, in one second of time; and the highest, that which is performed by 16,000 in the same period of time. It is stated, however, that a finely attuned ear is capable of appreciating, as a distinct sound, a kind of hissing noise occasioned by the performance of 48,000 half vibrations, or 24,000 impulses, in a second of time.

384. *Scale of musical notes.*—The principal notes, or musical sounds, are seven in number. In this country they are designated by the first seven letters of the alphabet in a peculiar arrangement, as C, D, E, F, G, A, B. On the con-

tinent, the seven syllables, Do, Re, Mi, Fa, Sol, La, Si, are usually preferred. These *notes* constitute what is called the *gamut*, or *diatonic scale*. On investigating the cause why this combination of seven sounds strikes the ear with agreeable sensations, it is found to depend on the simplicity of the relation between the notes, with reference to the number of their vibrations. Such a relation is called an *interval*. The simplest interval of musical sounds is that in which the higher note performs twice as many vibrations as the *fundamental note* from which it is derived. Such an interval is called an *octave*, and its relation is therefore as 1 is to 2, 2 to 4, 4 to 8, &c. A collection of eight consecutive notes constitutes an octave; the first of these, supposing it to be C, performs 258 vibrations in a second of time, while the eighth, also called C, performs 516 vibrations in the same space of time; the latter note is commonly said to be pitched *an octave higher* than the former. By way of illustrating this fact, let us suppose that a cord of forty-five inches in length, stretched between two pegs on a board, as in the piano-forte, produces the note C of 258 vibrations in a second. Let the cord be now pressed down by the finger exactly in the centre, and either half of it be struck, or made to vibrate; the consequence will be that a much shriller, or higher, note will be produced. This note is also called C, but it is the first note of a new series, and, for its production, 516 vibrations were performed in a second of time. This is upper C, or the octave of the fundamental C, which was produced by half the number of vibrations. Each of the seven notes is capable of being raised an octave higher by a similar experiment.

385. Between the fundamental interval of the *octave*, there exist many other intervals, of which, however, there are but six, which, when heard in succession, fall in unison upon the ear. In investigating the characters of these notes, we cannot help being struck with the fact, that the science of music, apparently so independent of abstract mathematics, is nevertheless based on certain fixed relations of numbers; and that the harmony of notes is intimately connected with the coincidence of simple numerical ratios. Assuming the cord of forty-five inches, above mentioned, to yield the note C, and calling it 1, its octave will require one half of the length of the cord; and the intermediate notes will require *lengths of cord* in the following proportions:—for D, eight-ninths; for E, four-fifths; for F, three-fourths; for G, two-thirds; for A,

three-fifths; and for B, eight-fifteenths. All these proportions are exactly reversed, with regard to the *number of vibrations*, which are, respectively, nine-eighths, five-fourths, four-thirds, three-seconds, five-thirds, and fifteen-eighths. All this will be rendered clearer by the following table, in which the names of the notes, the comparative lengths of the cord, and number of vibrations producing them, together with the absolute (approximate) number of vibrations performed in a second of time, in order to produce a particular note, are placed together:—

Names of Notes.		Comparative		Absolute (approximate) number of vibrations in a second.
Foreign.	English.	Length of Cord.	Number of Vibrations.	
Do	C	1	1	258
Re	D	$\frac{8}{9}$	$\frac{9}{8}$	290
Mi	E	$\frac{4}{5}$	$\frac{5}{4}$	322
Fa	F	$\frac{3}{4}$	$\frac{4}{3}$	344
Sol	G	$\frac{2}{3}$	$\frac{3}{2}$	387
La	A	$\frac{3}{5}$	$\frac{5}{3}$	430
Si	B	$\frac{8}{15}$	$\frac{15}{8}$	483
Do	C	$\frac{1}{2}$	2	516

386. Of the seven notes above described, there are three which are more apportioned to each other than the rest, and which consequently form the most agreeable combination to the ear. These are C, E, and G; and this chord of three notes is called a *triad.* In this case, also, it appears that the pleasurable emotion occasioned by the combination depends on the simplicity of the ratios of vibration, for in the time that C, or the fundamental note, performs 4 vibrations, its *third* E performs 5, and its *fifth* G, 6. This combination of the fundamental note C with the major third E and the fifth G is called the *perfect major chord.*

387. There are some curious facts connected with the harmonious notes. "The *cries* of a city—that is, the scarcely articulate, but often very musical, sounds uttered by persons selling things in the streets,—generally rise on *thirds* or *fifths*, sometimes on *octaves;* and this, although few of these poor people have been taught music. The cry of oysters by women in Edinburgh is always on an octave. Teachers of elocution are also aware that human beings in general make such transitions of voice naturally, under the influence of

certain feelings. For example, a person indifferently surprised at hearing a friend say, 'I was the person who did so and so,' will say, 'Was it you?' rising only a *third* at the last word. If greatly surprised, the rise will be a *fifth*. There may be even so great a degree of astonishment, that the word 'you' will begin on one note and terminate on its octave. The answers, 'Yes, it was I,' will show corresponding declensions or falls of voice. We thus see how truly music is a species of natural language. Unquestionably, every shade of human feeling can be represented by succession of its sounds, apart altogether from words."—*Chambers's Information for the People.*

388. The limits of this work will not admit of minute details of this interesting branch of Acoustics. A few remarks must, however, be added on the *chromatic scale*. By referring to the diatonic scale, above described, it will be observed that the seven intervals, though nearly equal, do not exactly, correspond: consequently, it is not possible to maintain the harmony of the notes, if any other than C be selected as the fundamental note. In order, therefore, that we may be enabled to select some other note than C, and at the same time, get rid of the inequalities subsisting between the seven intervals of the diatonic scale, *semitones* have been introduced between the *entire tones*, *i. e.* between the fundamental note and the second, between the second and the third, between the fourth and the fifth, between the fifth and the sixth, between the sixth and the seventh, and the octave is thus constituted of 8 entire tones, and 6 semitones. This scale, which contains 12 intervals, is called the *chromatic scale*. When the differences between the intervals are so far equalised, that the deviation from an exact ratio to the fundamental note is so small as to be imperceptible, an instrument, so tuned, is said to have an *even temperament.*

WIND, OR ATMOSPHERIC CURRENTS.

389. Wind is nothing more than air in motion, or an atmospheric current. As a natural phenomenon, that motion of the air which we call wind, is occasioned by the presence of a greater degree of heat in one place than in another: the air which has been heated, rises upward, while the surrounding portions move forward to occupy its place, and restore the equilibrium. The truth of this is illustrated by the fact, that during the burning of a house in a calm night, the

motion of the air towards the place where it is thus rarefied, makes the wind blow from every point towards the flame. On this subject, the reader is referred to what has been said at § 122, from which he will understand the importance of winds in the economy of nature, as tending to equalise the distribution of temperature over the globe. It will also be evident that the *general currents* of the atmosphere depend principally upon two circumstances, viz. the unequal temperature of the equator and of the poles, and the diurnal motion of the earth upon its axis.

390. The effect of *temperature* in the production of atmospheric currents, is strikingly exemplified in islands, situated in hot climates. "The land, during the daytime being under the rays of a tropical sun becomes heated in a greater degree than the surrounding ocean, and consequently there rises from the land a stream of warm air during the day, while the cooler air from the surface of the water, moving forward to supply this partial vacancy, produces a cool breeze setting inland on all sides of the island. This constitutes the *sea-breeze*, which is so delightful to the inhabitants of those hot countries, and without which the inhabitants could hardly exist in some of the most luxuriant islands between the tropics.

391. "During the night the motion of the air is reversed, because the earth, being heated superficially, soon cools when the sun is absent, while the water, being warmed several feet below its surface, retains its heat longer. Consequently, towards morning, the earth becomes colder than the water, and the air sinking down upon it, seeks an equilibrium by flowing outwards, like rays from a centre, and thus the *land-breeze* is produced. The wind then continues to blow from the land until the equilibrium is restored, or until the morning sun makes the land of the same temperature as the water, when for a time there will be a dead calm. Then again the land becoming warmer than the water, the sea-breeze returns as before, and thus the inhabitants of those sultry climates are constantly refreshed during the summer season with alternate land and sea-breezes.

392. "At the equator, which is a part of the earth continually under the heat of a burning sun, the air is expanded, and ascends upwards, so as to produce currents from the north and south, which move forward to supply the place of the heated air as it rises. These two currents, coming from

latitudes where the daily motion of the earth is less than at the equator, do not obtain its full rate of motion, and therefore, when they approach the equator, do not move so fast eastward as that portion of the earth, by the difference between the equator's velocity and that of the latitudes from which they come. This wind therefore falls behind the earth in her diurnal motion, and consequently has a relative motion towards the west. This constant breeze towards the west is called the *trade-wind*, because a large portion of the commerce of nations comes within its influence. While the air in the lower regions of the atmosphere is thus constantly flowing from the north and south towards the equator, and forming the trade-winds between the tropics, the heated air from these regions as perpetually rises and forms a counter current through the higher regions towards the north and south from the tropics, thus restoring the equilibrium.

393. "This counter motion of the air in the upper and lower regions is illustrated by a very simple experiment. Open a door a few inches, leading into a heated room, and hold a lighted candle at the top of the passage, the current of air, as indicated by the direction of the flame, will be *out* of the room. Then set the candle on the floor, and it will show that the current is there *into* the room. Thus, while the heated air rises and passes out of the room, that which is colder flows in, along the floor, to take its place. This explains the reason why our feet are apt to suffer with the cold, in a room moderately heated, while the other parts of the body are comfortable. It also explains why those who sit in the gallery of a church are sufficiently warm, while those who sit below may be shivering with cold. From such facts, showing the tendency of heated air to ascend, while that which is colder moves forward to supply its place, it is easy to account for the reason why the wind blows perpetually from the north and south towards the tropics; for the air being heated, as stated above, it ascends, and then flows north and south towards the poles, until, growing cold, it sinks down, and again flows towards the equator. The reader is again referred, for an illustration of these remarks, to § 122.

QUESTIONS ON CHAP. VII.

359. WHAT is meant by undulations, vibrations, or oscillations? What solid bodies possess this property? Explain the three kinds of vibration which occur in solid bodies of lineal form. Explain the undulations of liquid bodies. What is the effect of an impulse communicated to a fluid body?—360. What is meant by Acoustics? When a sonorous body is struck, in what manner do we gain from it the sensation of sound? Explain the analogy supposed to exist between the phenomena of sound and those of sight.—361. How is it proved that sound is conveyed to the ear by the medium of the air?—362. When the air is more dense than usual, how does it affect sound? What is said of the effects of sound on the tops of high mountains?—363. Which are the best conductors of sound, solid or elastic substances? What is said of the earth as a conductor of sound? How is it said that the Indians discover the approach of horses or men?

364. How is the rate of velocity of sound estimated? Does sound travel at a uniform rate? How may the velocity with which the report of a gun travels, be estimated?—365. At what velocity does sound travel through the atmosphere? Describe the effect produced by the report of a cannon at the distance of thirteen miles. How may this effect be explained? What difference is observed in the quality of sound proceeding from a long and from a short distance? What circumstances should be taken into consideration, in estimating the velocity of sound through the air?—366. To what extent does the velocity of sound through the air differ in different seasons throughout the year?—367. How may the distance of a thunder-cloud be determined by the velocity of sound?—368. Which convey sounds with the greatest velocity, solid substances, or air? Describe the experiment proving that sound is conducted by a metal with greater velocity than by the air.

369. In what lines does sound move?—370. From what kind of surface is sound reflected, so as to produce an echo? Explain Fig. 142.—371. Explain Fig. 143, and show in what direction sound approaches and leaves a reflecting surface.—372. What is the angle under which sound strikes a reflecting surface called? What is the angle under which it leaves a reflecting surface called? Is there any difference in the quantity of these two angles?—373. Suppose a pistol to be fired in the centre of a circular room, where would be the echo? Explain Fig. 144, and give the reason.—374. Suppose a sound to be produced

in one of the foci of an ellipse, where then might it be distinctly heard? Explain Fig. 146, and give the reason.—375. By what means may a repetition of reflected sounds be heard?—376. How is reflected sound affected by distance? What is the rate of distance at which a certain number of syllables may be echoed?—377. Why is it that persons can converse on the opposite sides of a river, when they could not hear each other at the same distance over the land? At what distance has the human voice been heard?

378. How is tone produced by the string of a violin or pianoforte?—379. On what does the difference between a *grave* and a *sharp* tone depend? Why are the bass strings of instruments covered with metallic wire?—380. Why does the Æolian harp yield a variety of tones, since all the strings are tuned in unison?—381. Explain Fig. 148, showing the manner in which strings vibrate in parts.—382. What constitutes a musical sound? What is meant by the quantity of a sound? What, by its quality?—383. Within what limits is the human ear capable of appreciating musical sounds?

384. What are the principal notes of music termed? On what does the agreeable sensation produced by them in succession depend? What is an octave? What relation exists between the fundamental note and its octave? How may this be illustrated?—385. How many intervals occur in unison between the fundamental interval of the octave? Assuming the cord of forty-five inches to yield the fundamental note C, and calling this cord 1, what length of cord will be required to form the other notes of the diatonic scale? What is the proportion of the number of vibrations to the lengths of cord, respectively?—386. What is a triad, and of what notes is it composed? On what does the pleasurable emotion produced by the triad depend?—387. Show that music is a natural language by some familiar illustrations.—388. What is the use of semitones? What is the chromatic scale?

389. What is wind? As a natural phenomenon, how is wind produced, or what is the cause of wind? How is this illustrated?—390, 391. In the islands of hot climates, why does the wind blow inland during the day, and off the land during the night? What are these breezes called?—392. What is said of the ascent of heated air at the equator? What is the consequence on the air towards the north and south? How are the trade-winds formed? While the air in the lower regions flows from the north and south towards the equator, in what direction does it flow in higher regions?—393. How is this counter current in lower and upper regions illustrated by a simple experiment?

CHAP. VIII.

OF OPTICS.

394. **Optics** is that branch of natural philosophy which treats of the phenomena of light and vision. In order to render the science of optics intelligible, it is necessary to explain several terms, which, although in common use, have a technical meaning, when applied in this science.

395. *Light* is the agent by which bodies are rendered perceptible to the sight. Its nature has always been involved in considerable mystery. According to the theory of *emission*, propounded by Newton, light has a material existence, and consists of minute particles of a very subtil nature, which emanate from luminous bodies in right lines with inconceivable velocity. According to the *undulatory* theory of more recent writers, light has no material existence, but its effects are produced by vibrations, or undulations, of a subtil ethereal medium universally diffused through nature; according to this view, the phenomena of light are produced by pulsations of ether on the retina of the eye, as those of sound are by pulsations of air on the nerve of hearing. Whatever may be the nature or cause of light, it has certain properties or effects which we are enabled to investigate. Thus, we can determine, experimentally, the laws by which it is governed in its passage through different transparent substances, and also those by which it is governed when it strikes a substance through which it cannot pass. We are also enabled to test its nature, to a certain degree, by decomposing or dividing it into its elementary parts.

396. *Luminous* bodies are such as emit, or excite the perception of, light from their own substance. Of this kind are the sun, the stars, terrestrial flames of all kinds, phosphorescent bodies, and those substances which shine by being heated, or by friction. *Non-luminous* bodies are those which have not the power of emitting, or exciting the sensation of, light from their own substance, but possess the property of reflecting the light which is cast upon them from luminous bodies. To this class belong the moon and planets, which shine by reflecting the light of the sun. Non-luminous bodies may illuminate each other, but their reflected light is inferior, in point of brilliancy, to that which proceeds from luminous bodies.

397. "*Transparent* bodies are such as permit the rays of light to pass freely through them. Air and some of the gases are perfectly transparent, since they transmit light without being visible themselves. Glass and water are also considered transparent, but they are not perfectly so, since they are themselves visible, and therefore do not suffer the light to pass through them without interruption. *Translucent* bodies are such as permit the light to pass, but not in sufficient quantity to render objects distinct when seen through them." These bodies may be termed *semi-transparent*, and they differ from perfectly transparent substances, in not admitting any colour, distance, or form, to be seen through them. *Opaque* bodies are the reverse of the transparent, in not transmitting any light through their substance. But their opacity is occasioned rather by their thickness than their absolute impermeability to light. Gold is considered opaque, but the rays of a candle, or of the sun, falling on a sheet of gold leaf laid on glass, are transmitted as a faint green glimmering light.

398. A body is said to be *illuminated*, when it is rendered visible by light. Every object exposed to the sun is illuminated. A lamp illuminates a room, and every object in it.

399. "A *ray* is a single line of light, as it comes from a luminous body. A *beam* of light is a body of parallel rays. A *pencil* of light is a body of diverging or converging rays. *Divergent* rays are such as come from a point, and continually separate wider apart, as they proceed. *Convergent* rays are those which approach each other, so as to meet at a common point. *Luminous* bodies emit rays, or pencils of light, in every direction, so that the space through which they are visible is filled with them at every possible point. Thus, the sun illuminates every point of space within the whole solar system. A light, as that of a light-house, which can be seen from the distance of ten miles in one direction, fills every point in a circuit of ten miles from it, with light. Were this not the case, the light from it could not be seen from every point within that circumference.

400. "The rays of light, like those of heat, move forward in straight lines from the luminous body, and are never turned out of their course except by some obstacle. Let A, Fig. 149, be a beam of light from the sun, passing through a small orifice in the window shutter, B. The sun cannot be seen through the crooked tube, C, because the beam, passing in a

straight line, strikes the side of the tube, and therefore does not pass through it.

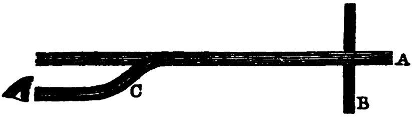


Fig. 149.

401. "All the illuminated bodies, whether natural or artificial, throw off light in every direction, of the same colour as themselves, though the light with which they are illuminated is white, or without colour. This fact is obvious to all who are endowed with sight. Thus, the light proceeding from grass is green, while that proceeding from a rose is red, and so of every other colour. We shall be convinced, in another place, that the white light by which objects are illuminated, is really composed of several colours, and that bodies *reflect* only the rays of their own colours, while they *absorb* all the other rays.

402. "Light moves with the amazing rapidity of about 95 millions of miles in 8¼ minutes, since it is proved, by certain astronomical observations, that the light of the sun reaches the earth in that time. This velocity is so great, that to any distance at which an artificial light can be seen, it seems to be transmitted instantaneously. If a ton of gunpowder were exploded on the top of a mountain, where its light could be seen a hundred miles, no perceptible difference would be observed in the time of its appearance on the spot, and at the distance of a hundred miles."

403. The intensity of light increases and diminishes inversely as the squares of the distance between the luminous and the illuminated body. This may be illustrated by a

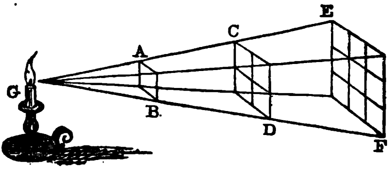
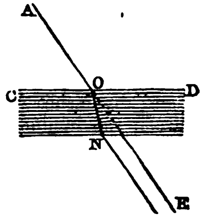


Fig. 150.

simple experiment. If a board a foot square A B be placed at the distance of one foot from a candle G, it will hide the light from a second board of two feet square C D, placed at the distance of two feet from the candle; or, of a board three feet square E F, placed at the distance of three feet from the candle. Now, a board of two feet square is *four* times as large as a board of one foot square; and a board of three feet square is *nine* times as large as that of one foot square; thus, the light, at double the distance, is spread over four times the surface, and at treble the distance over nine times the surface, it was spread over at the first distance. As the divergence *increases*, the intensity *decreases*. The application of this principle to the diminution of light which we should suffer on being removed further from the sun's influence, is obvious.

REFRACTION OF LIGHT.

404. "Although a ray of light will always pass in a straight line, when not interrupted, yet when it passes obliquely from one transparent body into another, of a different density, it leaves its linear direction, and is bent, or *refracted*, more or less, out of its former course. This change in the direction of light seems to arise from a certain power, or quality, which transparent bodies possess in different degrees; for some substances bend the rays of light much more obliquely than others.



Fg. 151.

405. "The manner in which the rays of light are refracted, may be readily understood by Fig. 151. Let A be a ray of the sun's light, proceeding obliquely towards the surface of the water C, D, and let E be the point which it would strike, if moving only through the air. Now, instead of passing through the water in the line A, E, it will be bent or refracted, on entering the water, from O to N, and having passed through the fluid, it is again refracted in a contrary direction on passing out of the water, and then proceeds onward in a straight line as before.

406. "The refraction of water is readily proved by the following simple experiment. Place an empty cup, Fig. 152, with a shilling on the bottom, in such a position that the

side of the cup will just hide the piece of money from the eye. Then let another person fill the cup with water, keeping the eye in the same position as before. As the water is poured in, the shilling will become visible, appearing to rise with the water. The effect of the water is to bend the ray of light coming from the shilling, so as to make it meet the eye below the point where it otherwise would. Thus the eye could not see the shilling in the direction of C, since the line of vision is towards A, and C is hidden by the side of the cup. But the refraction of the water bends the ray downwards, producing the same effect as though the object had been raised upwards, and hence it becomes visible.

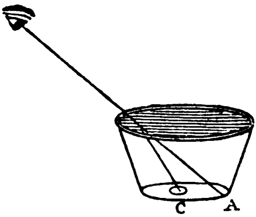


Fig. 152.

407. "The transparent body through which the light passes is called the *medium*, and it is found in all cases, '*that where a ray of light passes obliquely from one medium into another of a different density, it is refracted, or turned out of its former course.*' This is illustrated in the above examples, the water being a more dense medium than air. The refraction takes place at the surface of the medium, and the ray is refracted in its passage *out* of the refracting substance as well as *into* it.

408. "If the ray, after having passed through the water, then strikes upon a still more dense medium, as a pane of glass, it will again be refracted. It is understood, that in all cases the ray must fall upon the refracting medium obliquely, in order to be refracted, for if it proceeds from one medium to another perpendicularly to their surfaces, it will pass straight through them all, and no refraction will take place. Thus, in Fig. 153, let A represent air, B water, and C a piece of glass. The ray D, striking each medium in a perpendicular direction, passes through them all in a straight line. The oblique ray passes through the air in the direction of C, but meeting the water, is refracted in the direction of O; then falling upon the glass, it is again refracted in the direction of P, nearly parallel with the perpendicular line D.

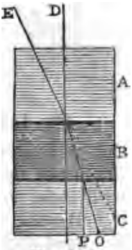


Fig. 153.

409. "*In all cases where the ray passes out of a rarer into a denser medium, it is refracted towards a perpendicular line, raised from the surface of the denser medium, and so, when it passes out of a denser, into a rarer medium, it is refracted from the same perpendicular.* Let the medium B, Fig. 154, be glass, and the medium C, water. The ray A, as it falls upon the medium B, is refracted *towards* the perpendicular line E, D; but when it enters the water, whose refractive power is less than that of glass, it is not bent so near the perpendicular as before, and hence it is refracted *from*, instead of towards, the perpendicular line, and approaches the original direction of the ray A, G, when passing through the air. The cause of refraction appears to be the power of attraction, which the denser medium exerts on the passing ray; and in all cases the attracting force acts in the direction of a perpendicular to the refracting surface.

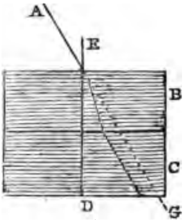


Fig. 154.

410. "The refraction of the rays of light, as they fall upon the surface of the water, is the reason why a straight rod, with one end in the water, and the other end rising above it, appears to be broken, or bent, and also to be shortened. Suppose the rod A, Fig. 155, to be set with one half of its length below the surface of the water, and the other half above it. The eye being placed in an oblique direction, will see the lower end apparently at the point O, while the real termination of the rod would be at N: the refraction will therefore make the rod appear shorter by the distance from O to N, or one-fourth shorter than the part below the water really is. The reason why the rod appears distorted, or broken, is, that we judge of the direction of the part which is under the water, by that which is above it; and the refraction of the rays coming from below the surface of the water, give them a different direction, when compared with those coming from that part of the rod which is above it. Hence, when the whole rod is below the water, no such distorted appearance is observed, because then all the rays are refracted equally.

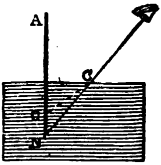


Fig. 155.

411. "For the reason just explained, persons are often deceived in respect to the depth of water, the refraction making it appear much more shallow than it really is; and there is no doubt but the most serious accidents have often happened to those who have gone into the water under such deception; for a pond which is really six feet deep, will appear to the eye only a little more than four feet deep.

REFLECTION OF LIGHT.

412. "If a ball be thrown against the side of a house swiftly, and in a perpendicular direction, it will bound back nearly in the line in which it was thrown, and may be caught with the hands; but if the ball be thrown obliquely to the right or left, it will bound away from the side of the house in the same relative direction in which it was thrown. The reflection of light, so far as regards the line of approach, and the line of leaving a reflecting surface, is governed by the same law. Thus, if a sun-beam, Fig. 156, passing through a small aperture in the window-shutter, A, be permitted to fall upon the plane mirror, or looking-glass, C D, at right angles, it will be reflected back at right angles with the mirror, and therefore will pass back again in exactly the same direction as that in which it approached.

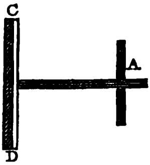


Fig. 156.

413. "But if the ray strike the mirror in an oblique direction, it will also be thrown off in an oblique direction, opposite to that in which it was thrown. If a ray pass towards a mirror in the line A C, Fig. 157, it will be reflected off in the direction of C D, making the angles 1 and 2 exactly equal. The ray, A C, is called the *incident* ray, and the ray, C D,

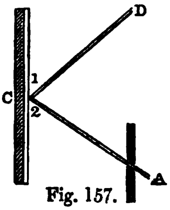


Fig. 157.

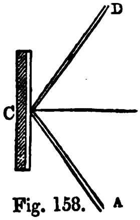


Fig. 158.

the *reflected* ray; and it is found in all cases, that whatever angle the ray of incidence makes with the reflecting surface, or with a perpendicular line drawn from the reflecting surface, exactly the same angle is made by the reflected ray.

414. "From these facts arises the general law in optics, that the *angle of reflection is equal to the angle of incidence.* The ray, A C, Fig. 158, is the ray of incidence, and that from C to D is the ray of reflection. The angles which A C make with the perpendicular line, and with the plane of the mirror, is exactly equal to those made by C D with the same perpendicular, and the same plane surface."

POLARIZATION OF LIGHT.

415. When a ray of light has been *reflected* from the *surface*, or *transmitted* through the *substance*, of any homogeneous uncrystallized body, the property of the reflected or transmitted light continues the same, so long as the light falls on the first surface always at the same angle; that is, the different *sides* of the rays exhibit no difference of property, in relation to the plane of its incidence. Such light is called *common light.* But when the body, from which the ray is reflected, or through which it is transmitted, is turned round so that the light falls upon it at one particular angle, the properties of the reflected or transmitted light are *changed:* it has acquired the property of entering transparent bodies at certain angles, and not at any others. Hence it follows, that the different *sides* of such rays have different properties in relation to the plane of their incidence. Such light is termed *polarized light*, in consequence of its rays having *poles*, or sides with different properties, like those of a magnetic bar. Polarized light may be procured in three ways:—1, by *reflection* from the surfaces of transparent and opaque bodies;—2, by *transmission* through a number of plates or planes of uncrystallized bodies;—and, 3, by transmission through bodies regularly crystallized, and possessing the property of double refraction.

416. One of the properties of *polarized light* consists in its *not* being reflected, like common light, when it falls upon a second reflector. In the following figure, S I is a ray of light falling upon the vertical glass A, at an angle of incidence of 56°; it is then reflected in the direction I R upon the glass B at the same angle of incidence of 56°; and from this second glass it is reflected to E, where the eye is placed to

receive it. In this apparatus, in which the *first* reflection is in a *horizontal* plane S I R, the *second* in a *vertical* plane I R E, the ray R E will be so weak as to be scarcely visible,

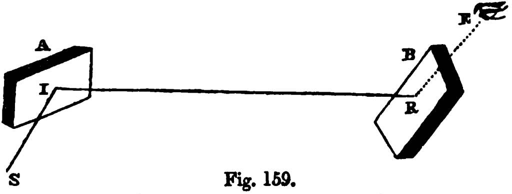


Fig. 159.

having almost entirely passed through the glass B, or become extinguished. But if the glass B be turned round (the ray I R being the axis of motion,) the ray R E will become more and more vivid, till the glass plate has been turned round 90°; at this point the plane of reflection I R E will be horizontal, like that of S I R, and at this point the whole of the ray R E will be reflected. On continuing to turn the plate, the ray will become gradually fainter, until, after having turned the plate 90° more, the ray becomes again invisible, the plane I R E being again vertical to the plane S I R. On a further motion of 90°, the ray resumes its vividness, the two planes being again horizontal; and, on completing the circle, by turning the plate 90° more, it is brought to its first position, and the ray is again invisible. Hence it may be stated as a *law* that, when the plane of the second reflector is *perpendicular* to the first, and the ray falls at an angle of 56°, it is not reflected at all, but *disappears;* but that, when the plane is *parallel*, the ray is entirely reflected. The maximum polarizing angle for glass is, therefore, 56°; that of water is 52° 45′.

417. By the application of *polarized light*, many substances, which were formerly supposed to be homogeneous in their structure, have been found to present a very curious organization. It has been applied to the investigation of several mineral, vegetable, and animal structures.

MIRRORS.

418. " *Mirrors* are of three kinds, namely, *plane*, *convex*, and *concave*. They are made of polished metal, or of glass covered on the back with an amalgam of tin and quicksilver.

419. "The common *looking-glass* is a plane mirror, and consists of a plate of ground glass so highly polished as to permit the rays of light to pass through it with little interruption. On the back of this plate is placed the reflecting surface, which consists of a mixture of tin and mercury. The glass plate, therefore, only answers the purpose of sustaining the metallic surface in its place, of admitting the rays of light to and from it, and of preventing its surface from tarnishing, by excluding the air. Could the metallic surface be retained in its place, and not exposed to the air, without the glass plate, these mirrors would be much more perfect than they are, since, in practice, glass cannot be made so perfect as to transmit all the rays of light which fall on its surface.

420. "When applied to the plane mirror, the angles of incidence and of reflection are equal, as already stated; and it therefore follows, that when the rays of light fall upon it obliquely in one direction, they are thrown off under the same angle in the opposite direction. This is the reason why the images of objects can be seen when the objects themselves are not visible. Suppose the mirror A B, Fig. 160, to be placed on the side of a room, and a lamp to be set in another room, but so situated that its light would shine upon the glass. The lamp itself could not be seen by the eye placed at E, because the partition D is between them; but its image would be visible at E, because the angle of the incident ray, coming from the light, and that of the reflected ray which reaches the eye, are equal.

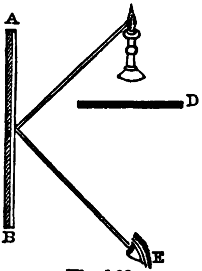


Fig. 160.

421. "An image from a plain mirror appears to be just as far behind the mirror as the object is before it, so that when a person approaches this mirror, his image seems to come forward to meet him; and when he withdraws from it, his image appears to be moving backward at the same rate. For the same reason, the different parts of the same object will appear to extend as far behind the mirror, as they are before it. If, for instance, one end of a rod, two feet long, be made to touch the surface of such a mirror, this end of the rod, and its image, will seem nearly to touch each other, there being only the thickness of the glass between them; while the

other end of the rod, and the other end of its image, will appear to be equally distant from the point of contact.

422. "The reason of this is explained on the principle, that the angle of incidence and that of reflection are equal. Suppose the arrow A, to be the object reflected by the mirror D C, Fig. 161, the incident rays A, flowing from the end of the arrow, being thrown back by reflection, will meet the eye in the same state of divergence that they would do, if they proceeded to the same distance behind the mirror, that the eye is before it, as at O. Therefore, by the same law, the reflected rays, where they meet the eye at E, appear to diverge from a point H, just as far behind the mirror, as A is before it, and consequently the end of the arrow most remote from the glass, will appear to be at H, or the point where the approaching rays would meet, were they continued onward behind the glass. The rays flowing from every other part of the arrow follow the same law; and thus every part of the image seems to be at the same distance behind the mirror, that the object really is before it.

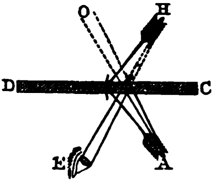


Fig. 161.

423. "In a plain mirror, a person may see his whole image, when the mirror is only half as long as himself, let him stand at any distance from it whatever. This is also explained by the law, that the angles of incidence and reflection are equal. If the mirror be elevated, so that the ray of light from the eye fall perpendicularly upon the mirror, this ray will be thrown back by reflection in the same direction, so that the incident and reflected ray by which the image of the eyes and face is formed, will be nearly parallel, while the ray flowing from his feet will fall on the mirror obliquely, and will be reflected as obliquely in the contrary direction; and so of all the other rays by which the image of the different parts of the person is formed.

424. "Thus, suppose the mirror C E, Fig. 162, to be just half as long as the arrow placed before it, and suppose the eye to be placed at A. Then the ray A E, proceeding from the eye at A, and falling perpendicularly on the glass at E, will be reflected back to the eye in the same line, and this part of the image will appear at B, in the same line, and at the same distance behind the glass, that the arrow is

before it. But the ray flowing from the lower extremity of the arrow, will fall on the mirror obliquely, as at E, and will be reflected under the same angle to the eye, and therefore the extremity of the image, appearing in the direction of the reflected ray, will be seen at D. The rays flowing from the other parts of the arrow, will observe the same law, and thus the whole image is seen distinctly, and in the same position as the object.

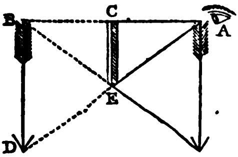


Fig. 162.

425. "To render this still more obvious, suppose the mirror to be removed, and another arrow to be placed in the position where its image appears, behind the mirror, of the same length as the one before it. Then the eye, being in the same position as represented in the figure, would see the different parts of the real arrow in the same direction that it before saw the image. Thus, the ray flowing from the upper extremity of the arrow, would meet the eye in the direction of B C, while the ray, coming from the lower extremity, would fall on it in the direction of E D.

426. "Convex mirror.—A convex mirror is a part of a sphere, or globe, reflecting from the outside. Suppose Fig. 163 to be a sphere, then the part from A to O would be a section of the sphere. Any part of a hollow ball of glass, with an amalgam of tin and quicksilver spread on the inside, or any part of a metallic globe polished on the outside, would form a convex mirror. The *axis* of a convex mirror, is a line, as C B, passing through its centre.

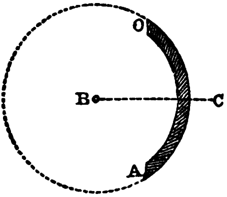


Fig. 163.

427. "Rays of light are said to *diverge*, when they proceed from the same point, and constantly recede from each other, as from the point A, Fig. 164. Rays of light are said to *converge*, when they approach each other in such a direction as finally to meet at a point, as at B, Fig. 164.

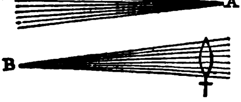


Fig. 164.

428. "The image formed by a plane mirror, as we have already seen, is of the same size as the object, but the image reflected from the convex mirror is always smaller than the object.

429. "The law which governs the passage of light with respect to the angles of incidence and reflection, to and from the convex mirror, is the same as already stated for the plane mirror.

430. "From the surface of a plane mirror, parallel rays are reflected parallel; but the convex mirror causes parallel rays falling on its surface to *diverge*, by reflection. To make this understood, let 1, 2, 3, Fig. 165, be parallel rays, falling on the surface of the convex reflector, of which A would be the centre, were the reflector a whole sphere. The ray 2 is perpendicular to the surface of the mirror, for when continued in the same direction, it strikes the axis, or centre of the circle A. The two rays, 1 and 3, being parallel to this, all three would fall on a plane mirror in a perpendicular direction, and consequently would be reflected in the lines of their incidence. But the obliquity of the convex surface, it is obvious, will render the direction of the rays 1 and 3, oblique to that surface, for the same reason that 2 is perpendicular to that part of the circle on which it falls. Rays falling on any part of this mirror, in a direction which, if continued through the circumference, would strike the centre, are perpendicular to the side where they fall. Thus, the dotted lines, C A and D A, are perpendicular to the surface, as well as 2.

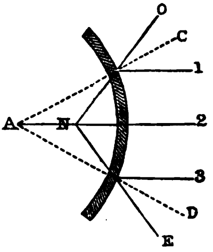


Fig. 165.

431. "Now the reflection of the ray 2, will be back in the line of its incidence, but the rays 1 and 3, falling obliquely, are reflected under the same angles at which they fall, and therefore their lines of reflection will be as far without the perpendicular lines C A, and D A, as the lines of their incident rays, 1 and 3, are within them, and consequently they will diverge in the direction of E and O; and since we always see the image in the direction of the reflected ray, an object placed at 1, would appear behind the surface of the mirror at N, or in the direction of the line O N.

432. "Perhaps the subject of the convex mirror will be better understood, by considering its surface to be formed of a number of plane surfaces, indefinitely small. In this case, each point from which a ray is reflected, would act in the same manner as a plane mirror, and the whole in the manner of a number of minute mirrors inclined from each other. Suppose A and B, Fig. 166, to be the points on a convex mirror from which the two parallel rays, C and D, are reflected. Now, from the surface of a plane mirror, the reflected rays would be parallel, whenever the incident ones are so, because each will fall upon the surface under the same angles. But it is obvious, in the present case, that these rays fall upon the surfaces, A and B, under different angles, as respects the surfaces, C approaching in a more oblique direction than D; consequently C is reflected more obliquely than D, and the two reflected rays, instead of being parallel as before, diverge in the direction of N and O.

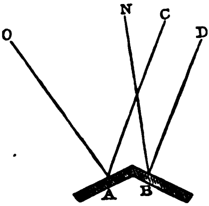


Fig. 166.

433. "Again, the two converging rays, A and B, Fig. 167, without the interposition of the reflecting surfaces, would meet at C, but because the angles of reflection are equal to those of incidence, and because the surfaces of reflection are inclined to each other, these rays are reflected less convergent, and instead of meeting at the same distance before the mirror that C is behind it, are sent off in the direction of E, at which point they meet. '*Thus, parallel rays falling on a convex mirror, are rendered diverging by reflection; converging rays are made less convergent, or parallel, and diverging rays more divergent.*'

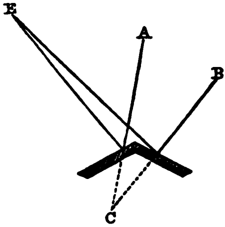


Fig. 167.

434. "The effect of the convex mirror, therefore, is to disperse the rays of light in all directions; and it is proper here to remind the pupil, that although the rays of light are represented on paper by single lines, there are in fact probably millions of rays, proceeding from every point of all visible bodies. Only a comparatively small number of these rays,

it is true, can enter the eye, for it is only by those which proceed in straight lines from the different parts of the object, and enter the pupil, that the sense of vision is excited. Now, to conceive how exceedingly small must be the proportion of light thrown off, from any visible object which enters the eye, we must consider that the same object reflects rays in every other direction, as well as in that in which it is seen. Thus, the gilded ball on the steeple of a church may be seen by millions of persons at the same time, who stand upon the ground; and were millions more raised above these, it would be visible to all. When, therefore, it is said, that the convex mirror disperses the rays of light which fall upon it from any object, and when the direction of these reflected rays are shown only by single lines, it must be remembered, that each line represents pencils of rays, and that the light not only flows from the parts of the object thus designated, but from all the other parts. Were this not the case, the object would be visible only at certain points.

435. "The images of objects reflected from the convex mirror, appear curved, because their different parts are not equally distant from its surface. If the object A, be placed obliquely before the convex mirror, Fig. 168, then the converging rays from its two extremities, falling obliquely on its surface, would, were they prolonged through the mirror, meet at the point C behind it. But instead of being thus continued, they are thrown back by the mirror, in less convergent lines, which meet the eye at E, it being, as we have seen, one of the properties of this mirror, to reflect converging rays less convergent than before.

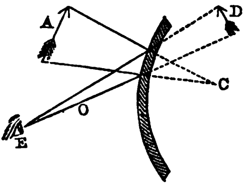


Fig. 168.

436. "The image being always seen in the direction from which the rays approach the eye, it appears behind the mirror at D. If the eye be kept in the same position, and the object, A, be moved further from the mirror, its image will appear smaller, in a proportion inversely to the distance to which it is removed. Consequently, by the same law, the two ends of a straight object will appear smaller than its middle, because they are further from the reflecting surface of the mirror. Thus, the images of straight objects, held before

a convex mirror, appear curved, and for the same reason, the features of the face appear out of proportion, the nose being too large, and the cheeks too small, or narrow.

437. "The reason why the image appears less than the object, is, that the convex surface of the mirror has the property, as stated above, of decreasing the convergency of the incidental rays by reflection.

438. "Now, objects appear to us large or small in proportion to the angle which the rays of light, proceeding from their extreme parts, form, when they meet at the eye. For it is plain that the half of any object will appear under a less angle than the whole, and the quarter under a less angle still. Therefore, the smaller an object is, the smaller will be the angle under which it will appear at a given distance. If then a mirror make the angle under which an object is seen smaller, the object itself will seem smaller than it really is. Hence the image of an object, when reflected from the convex mirror, appears smaller than the object itself. This will be understood by Fig. 169.

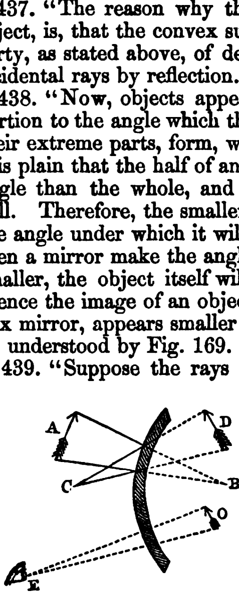


Fig. 169.

439. "Suppose the rays flowing from the extremities of the object A, to be reflected back to C, under the same degrees of convergence at which they strike the mirror; then, as in the plane mirror, the image D would appear of the same size as the object A; for if the rays from A were prolonged behind the mirror, they would meet at B, but forming the same angle, by reflection, that they would do, if thus prolonged, the object seen from B, and its image from C, would appear of the same dimensions. But, instead of this, the rays from the arrow A, being rendered less convergent by reflection, are continued onward, and meet the eye under a more acute angle than at C, the angle under which they actually meet being represented at E, consequently the image of the object is shortened in proportion to the acuteness of this angle, and the object appears diminished, as represented at O.

440. "The image of an object, as already stated, appears less as the object is removed to a greater distance from the mirror. To explain the reason of this, let us suppose that

the arrow A, Fig. 170, is diminished by reflection from the convex surface, so that its image appearing at D, with the eye at C, shall seem as much smaller in proportion to the object, as D is less than A. Now, keeping the eye at the same distance from the mirror, withdraw the object, so that it shall be equally distant with the eye, and the image will gradually diminish, as the arrow is removed

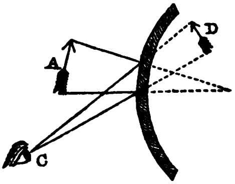


Fig. 170.

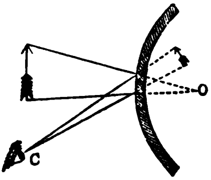


Fig. 171.

441. "The reason of this will be made plain by the next figure; for as the arrow is moved backwards, the angle at C, Fig. 171, must be diminished, because the rays flowing from the extremities of the object fall a greater distance before they reach the surface of the mirror; and as the angles of the reflected rays bear a proportion to those of the incident ones, so the angle of vision will become less in proportion as the object is withdrawn. The effect, therefore, of withdrawing the object, is first to lessen the distance between the converging rays, flowing from it, at the point where they strike the mirror, and, as a consequence, to diminish the angle under which the reflected rays convey its image to the eye.

442. "In the plane mirror, as already shown, the image appears exactly as far behind the mirror as the object is before it, but the convex mirror shows the image just under the surface, or, when the object is removed to a distance, a little way behind it. To understand the reason of this difference, it must be remembered, that the plane mirror makes the image seem as far behind as the object is before it, because the rays are reflected in the same relative position at which they fall upon its surface. Thus, parallel rays are reflected parallel; divergent rays equally divergent; and convergent rays equally convergent. But the convex mirror, as also above shown, reflects convergent rays less convergent,

and divergent rays more divergent, and it is from this property of the convex mirror that the image appears near its surface, and not as far behind it as the object is before it, as in the plane mirror.

443. "Let us suppose that A, Fig. 172, is a luminous point, from which a pencil of diverging rays falls upon a convex mirror. These rays, as already demonstrated, will be reflected more divergent, and consequently will meet the eye at E, in a wider state of dispersion than they fell upon the mirror at O. Now, as the image will appear at the point where the diverging rays would converge to a focus in a contrary direction, were they prolonged behind the mirror, so it cannot appear as far behind the reflecting surface as the object is before it, for the more widely the rays meeting at the eye are separated, the shorter will be the distance at which they will come to a point. The image will, therefore, appear at N, instead of appearing at an equal distance behind the mirror that the object A is before it.

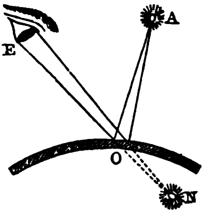


Fig. 172.

444. CONCAVE MIRROR.—"The shape of the *concave mirror* is exactly like that of the convex mirror, the only difference between them being in respect to their reflecting surfaces. The reflection of the concave mirror takes place from its inside, or concave surface, while that of the convex mirror is from the outside, or convex surface. Thus the section of a metallic sphere, polished on both sides, is both a concave and convex mirror, as one or the other side is employed for reflection. The effect and phenomena of this mirror will therefore be, in many respects, directly the contrary from those already detailed in reference to the convex mirror.

445. "From the *plane* mirror the relation of the incident rays is not changed by reflection; from the *convex* mirror they are dispersed; but the *concave* mirror renders the rays reflected from it more convergent, and tends to concentrate them into a focus. The surface of the concave mirror, like that of the convex, may be considered as a great number of minute plane mirrors, inclined to each other at certain angles, in proportion to its concavity.

446. "The laws of incidence and reflection are the same,

when applied to the concave mirror, as those already explained in reference to the other mirrors. In reference to the concave mirror, let us, in the first place, examine the effect of two plane mirrors inclined to each other, as in Fig. 173, on parallel rays of light. The incident rays, A and B, being parallel before they reach the reflectors, are thrown off at unequal angles in respect to each other, for B falls on the mirror more obliquely than A, and consequently is thrown off more obliquely in a contrary direction, therefore, the angles of reflection being equal to those of incidence, the two rays meet at C. Thus we see that the effect of two plane mirrors inclined to each other, is to make parallel rays converge and meet in a focus. The same result would take place, whether the mirror was one continued circle, or an infinite number of small mirrors inclined to each other, in the same relation as the different parts of the circle. The effect of this mirror, as we have seen, being to render parallel rays convergent, the same principle will render diverging rays parallel, and converging rays still more convergent.

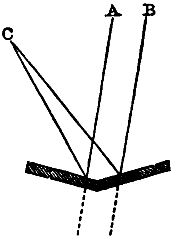


Fig. 173.

447. "The *focus* of a concave mirror is the point where the rays are brought together by reflection. The *centre of concavity* in a concave mirror, is the centre of the sphere, of which the mirror is a part. In all concave mirrors, the focus of parallel rays, or rays falling directly from the sun, is at the distance of half the semi-diameter of the sphere, or globe, of which the reflector is a part. Thus, the parallel rays 1, 2, 3, &c., Fig. 174, all meet at the point O, which is half the distance between the centre A, of the whole sphere, and the surface of the reflector, and therefore one quarter the diameter of the whole sphere, of which the mirror is a part.

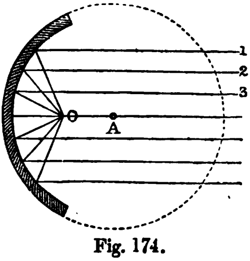


Fig. 174.

448. "In concave mirrors, of all dimensions, the reflected rays follow the same law; that is, parallel rays meet and cross each other at the distance of one-fourth the diameter of the sphere

of which they are sections. This point is called the *principal* focus of the reflector.

449. "But if the incident rays are divergent, the focus will be removed to a greater distance from the surface of the mirror, than when they are parallel, in proportion to their divergency. This might be inferred from the general laws of incidence and reflection, but will be made obvious by Fig. 175, where the diverging rays 1, 2, 3, 4, form a focus at the point O, whereas, had they been parallel, their focus would have been at A. That is, the actual focus is at the centre of the sphere, instead of being half way between the centre and circumference, as is the case when the incident rays are parallel. The real focus, therefore, is beyond, or without, the principal focus of the mirror.

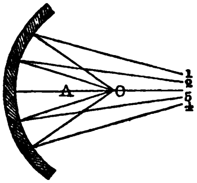


Fig. 175.

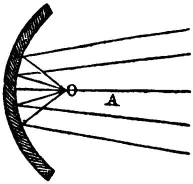


Fig. 176.

450. "By the same law, converging rays will form a point within the principal focus of a mirror. Thus, were the rays falling on the mirror, Fig. 176, parallel, the focus would be at A; but in consequence of their previous convergency, they are brought together at a less distance than the principal focus, and meet at O.

451. "The images of objects reflected by a convex mirror, we have seen, are smaller than the objects themselves. But the concave mirror, when the object is nearer to it than the principal focus, presents the image larger than the object, erect, and behind the mirror. To explain this, let us suppose the object A, Fig. 177, to be placed before the mirror, and nearer to it than the principal focus. Then the rays proceeding from the extremities of the object without

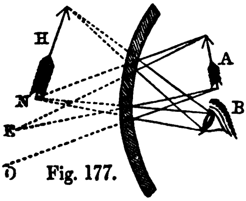


Fig. 177.

interruption, would continue to diverge in the lines O and N, as seen behind the mirror; but, by reflection, they are made to diverge less than before, and consequently to make the angle under which they meet more obtuse at the eye B, than it would be if they continued onward to E, where they would have met without reflection. The result, therefore, is to render the image H, upon the eye, as much larger than the object A, as the angle at the eye is more obtuse than the angle at E.

452. "On the contrary, if the object is placed more remote from the mirror than the principal focus, and between the focus and the centre of the sphere of which the reflector is a part, then the image will appear inverted on the contrary side of the centre, and farther from the mirror than the object; thus, if a lamp be placed obliquely before a concave mirror, as in Fig. 178, its image will be seen inverted in the air, on the contrary side of a perpendicular line through the centre of the mirror.

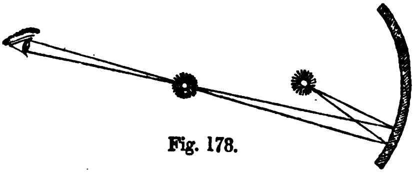


Fig. 178.

453. From the property of the concave mirror to form an inverted image of the object suspended in the air, many curious and surprising deceptions may be produced. Thus, when the mirror, the object, and the light, are placed so that they cannot be seen, (which may be done by placing a screen before the light, and permitting the reflected rays to pass through a small aperture in another screen,) the person mistakes the image of the object for its reality, and not understanding the deception, thinks he sees persons walking with their heads downwards, and cups of water turned bottom upwards, without spilling a drop. Again, he sees clusters of delicious fruit, and when invited to help himself, on reaching out his hand for that purpose, he finds that the object either suddenly vanishes from his sight, owing to his having moved his eye out of the proper range, or that it is intangible.

454. "This kind of deception may be illustrated by any one who has a concave mirror only of three or four inches in diameter, in the following manner: Suppose the tumbler A, to be filled with water, and placed beyond the principal focus of the concave mirror, Fig. 179, and so managed as to be hid from the eye C, by the screen B. The lamp by which the tumbler is illuminated must also be placed behind the screen, and near the tumbler. To a person placed at C, the tumbler with its contents will appear inverted at E, and suspended in the air. By carefully moving forward, and still keeping the eye in the same line with respect to the mirror, the person may pass his hand through the shadow of the tumbler; but without such conviction, any one unacquainted with such things, could hardly be made to believe that the image was not a reality. By placing another screen between the mirror and the image, and permitting the converging rays to pass through an aperture in it, the mirror may be nearly covered from the eye, and thus the deception would be increased.

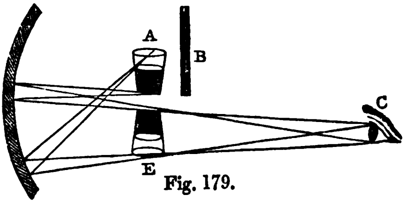


Fig. 179.

455. "The image reflected from a concave mirror, moves in the same direction with the object, when the object is within the principal focus; but when the object is more remote than the principal focus, the image moves in a contrary direction from the object, because the rays then cross each other. If a man place himself directly before a large concave mirror, but farther from it than the centre of concavity, he will see an inverted image of himself in the air, between him and the mirror, but less than himself. And if he hold out his hand towards the mirror, the hand of his image will come out toward his hand, and he may imagine that he can shake hands with his image. But if he reach his hand further towards the mirror, the hand of the image will pass by his hand, and come between his hand and his body; and if

he move his hand toward either side, the hand of the image will move in a contrary direction, so that if the object moves one way, the image will move the other.

456. "The concave mirror having the property of converging the rays of light, is equally efficient in concentrating the rays of heat, either separately, or with the light. When, therefore, such a mirror is presented to the rays of the sun, it brings them to a focus, so as to produce degrees of heat in proportion to the extent and perfection of its reflecting surface. A metallic mirror of this kind, of only four or six inches in diameter, will fuse metals, set wood on fire, &c.

457. "As the parallel rays of heat or light are brought to a focus at the distance of one quarter of the diameter of the sphere, of which the reflector is a section, so if a luminous or heated body be placed at this point, the rays from such body passing to the mirror will be reflected from all parts of its surface, in parallel lines; and the rays so reflected, by the same law, will be brought to a focus by another mirror standing opposite to this.

458. "Suppose a red hot ball to be placed in the principal focus of the mirror A, Fig. 180, the rays of heat and light proceeding from it will be reflected in the parallel lines 1, 2, 3, &c. The reason of this is the same as that which causes parallel rays, when falling on the mirror, to be converged to a focus. The angles of incidence being equal to those of reflection, it makes no difference in this respect, whether the rays pass to or from the focus. In one case, parallel incident rays from the sun, are concentrated by reflection; and in the other, incident diverging rays, from the heated ball, are made parallel by reflection. The rays therefore, flowing from the hot ball to the mirror A, are thrown into parallel

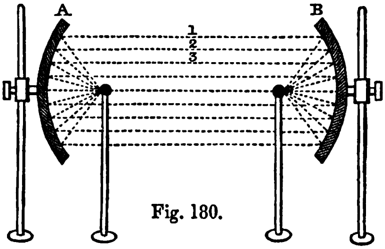


Fig. 180.

lines by reflection, and these reflected rays, in respect to the mirror B, become the rays of incidence, which are again brought to a focus by reflection. Thus the heat of the ball, by being placed in the focus of one mirror, is brought to a focus by the reflection of the other mirror.

459. "Several striking experiments may be made with a pair of concave mirrors placed facing each other, as in the figure. If a red hot ball be placed in the focus of A, and some gunpowder in the focus of B, the mirrors being ten or twenty feet apart, according to their dimensions, the powder will flash by the heat of the ball, concentrated by the second mirror. To show that it is not the direct heat of the ball which sets fire to the powder, a paper screen may be placed between the mirrors, until everything is ready. The operator will then only have to remove the screen, in order to flash the powder.

460. "To show that heat and light are separate principles, place a piece of phosphorus in the focus of B, and when the ball is so cool as not to be luminous, remove the screen, and the phosphorus will instantly inflame.

REFRACTION BY LENSES.

461. "*A lens* is a transparent body, generally made of glass, and so shaped that the rays of light in passing through it are either collected together or dispersed. Lens is a Latin word, signifying a *lentil*, or small flat bean.

"It has already been shown (§ 404), that when the rays of light pass from a rarer into a denser medium, they are refracted, or bent out of their former course, except when they happen to fall perpendicularly on the surface of the medium.

"The point where no refraction is produced on perpendicular rays, is called the *axis* of the lens, which is a right line passing through its centre, and perpendicular to both its surfaces.

"In every beam of light, the middle ray is called its *axis*.

"Rays of light are said to fall *directly* upon a lens, when their axes coincide with the axis of the lens; otherwise they are said to fall *obliquely*.

"The point at which the rays of the sun are collected, by passing through a lens, is called the *principal focus* of that lens.

462. "Lenses are of various kinds, and have received cer-

tain names, depending on their shapes. The different kinds are shown at Fig. 181.

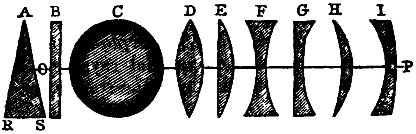


Fig. 181.

"A *prism*, seen at A, has two plane surfaces, A R, and A S, inclined to each other.

"A *plane glass*, shown at B, has two plane surfaces, parallel to each other.

"A *spherical lens*, C, is a ball of glass, and has every part of its surface at an equal distance from the centre.

"A *double convex lens*, D, is bounded by two *convex* surfaces, opposite to each other.

"A *plano-convex lens*, E, is bounded by a convex surface on one side, and a plane on the other.

"A *double-concave lens*, F, is bounded by two concave spherical surfaces, opposite to each other.

"A *plano-concave lens*, G, is bounded by a plane surface on one side, and a concave one on the other.

"A *meniscus*, H, is bounded by one concave and one convex spherical surface, which two surfaces meet at the edge of the lens.

"A *concavo-convex* lens, I, is bounded by a concave and convex surface, but which diverge from each other, if continued.

"The effects of the prism on the rays of light will be shown in another place. The refraction of the *plane* glass bends the parallel rays of light equally towards the perpendicular, as already shown. The *sphere* is not often employed as a lens, since it is inconvenient in use.

463. "CONVEX LENS.—It has been shown in a former part of this article, that when a ray of light passes obliquely out of a rarer into a denser medium, it is refracted, or turned out of its former course. Suppose, then, there is presented to the rays of light, a piece of glass, with its surface so shaped, that all the rays, except those which pass through its axis, are refracted towards the perpendicular, it is obvious that they would all finally meet the perpendicular ray, and there form a focus.

464. "The focal distances of convex lenses, depend on their degrees of convexity. The focal distance of a single, or plano-convex lens, is the diameter of a sphere, of which it is a section. If the whole circle, Fig. 182, be considered the circumference of a sphere, of which the *plano-convex* lens B A, is a section, then the focus of parallel rays, or the principal focus, will be at the opposite side of the sphere, or at C.

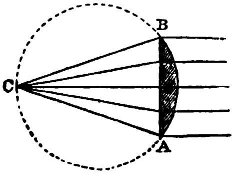


Fig. 182.

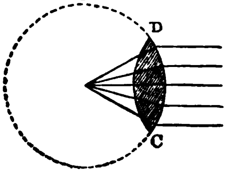


Fig. 183.

465. "The focal distance of a *double convex* lens, is the radius, or half the diameter of the sphere of which it is a part. Hence the plano-convex lens, being one half of the double convex lens, the latter has about twice the refractive power of the former; for the rays suffer the same degree of refraction in passing out of the one convex surface, that they do in passing into the other. The shape of the double convex lens, D C, Fig. 183, is that of two plano-convex lenses, placed with their plane surfaces in contact, and consequently the focal distance of this lens is nearly the centre of the sphere of which one of its surfaces is a part. If parallel rays fall on a convex lens, it is evident that the ray only which penetrates the axis and passes towards the centre of the sphere, will proceed without refraction, as shown in the above figures. All the others will be refracted so as to meet the perpendicular ray at a greater or less distance, depending on the convexity of the lens.

466. "If diverging rays fall on the surface of the same lens, they will, by refraction, be rendered less divergent, parallel, or convergent, according to the degrees of their divergency, and the convexity of the surface of the lens. Thus, the diverging rays 1, 2, &c., Fig. 184, are refracted by the lens A O,

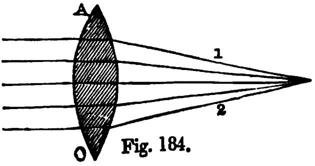


Fig. 184.

in a degree just sufficient to render them parallel, and therefore would pass off in right lines, indefinitely, or without ever forming a focus.

467. "It is obvious by the same law, that were the rays less divergent, or were the surface of the lens more convex, the rays in Fig. 184 would become convergent, instead of parallel, because the same refractive power which would render divergent rays parallel, would make parallel rays convergent, and converging rays still more convergent. Thus the pencils of converging rays, Fig. 185, are rendered still more convergent by their passage through the lens, and are therefore brought to a focus nearer the lens, in proportion to their previous convergency.

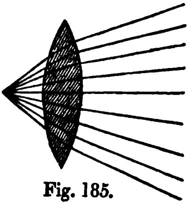


Fig. 185.

468. "The eye-glasses of spectacles for old people are double convex lenses, more or less spherical, according to the age of the person, or the magnifying power required. The common burning glasses, which are used for lighting cigars, and sometimes for kindling fires, are also convex lenses. Their effect is to concentrate to a focus, or point, the heat of the sun which falls on their whole surface; and hence the intensity of their effects is in proportion to the extent of their surfaces, and their focal lengths. One of the largest burning glasses ever constructed, was made by Mr Parker of London. It was three feet in diameter, with a focal distance of three feet nine inches. But in order to increase its power still more, he employed another lens about a foot in diameter, to bring its rays to a smaller focal point. This apparatus gave a most intense degree of heat, when the sun was clear, so that twenty grains of gold were melted by it in four seconds, and ten grains of platina, the most infusible of all metals, in three seconds.

469. "It has been explained, that the reason why the convex mirror diminishes the images of objects is, that the rays which come to the eye from the extreme parts of the object are rendered less convergent by reflection, from the convex surface, and that, in consequence, the angle of vision is made more acute. Now, the refractive power of the convex lens has exactly the contrary effect, since by converging the rays flowing from the extremities of an object, the visual angle is

rendered more obtuse, and therefore all objects seen through it appear magnified. Suppose the object A, Fig. 186, appears to the naked eye of the length represented in the drawing. Now, as the rays coming from each end of the object, form, by their convergence at the eye, the *visual angle*, or the angle under which the object is seen, and we call objects large or small in proportion as this angle is obtuse or acute, if therefore the object A be withdrawn further from the eye, it is apparent that the rays O O, proceeding from its extremities, will enter the eye under a more acute angle, and therefore, that the object will appear diminished in proportion. This is the reason why objects at a distance appear smaller than when near us. When near, the visual angle is increased, and when at a distance, it is diminished.

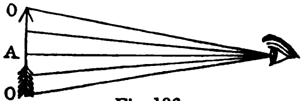


Fig. 186.

470. "The effect of the convex lens is to increase the visual angle, by bending the rays of light coming from the object, so as to make them meet at the eye more obtusely; and hence it has the same effect, in respect to the visual angle, as bringing the object nearer the eye. This is shown by Fig. 187, where it is obvious, that did the rays flowing from the extremities of the arrow meet the eye without refraction, the visual angle would be less, and therefore the object would appear shorter. Another effect of the convex lens, is to enable us to see objects nearer the eye, than without it, as will be explained under the article *vision*. Now, as the rays of light flow from all parts of a visible object of whatever shape, so the breadth, as well as the length, is increased by the convex lens, and thus the whole object appears magnified.

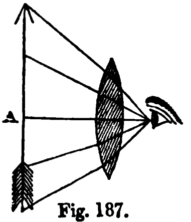


Fig. 187.

471. "CONCAVE LENS.—The effect of the concave lens is directly opposite to that of the convex. In other terms, by a concave lens, parallel rays are rendered diverging, converging rays have their convergency diminished, and diverging rays have their divergency increased, according to the concavity of the lens. These glasses, therefore, exhibit objects smaller than they really are, for by diminishing the conver-

gence of the rays coming from the extreme points of an object, the visual angle is rendered more acute, and hence the object appears diminished by this lens, for the opposite reason that it is increased by the convex lens.

472. "This will be made plain by the two following diagrams:—1. Suppose the object A B, Fig. 188, to be placed at such a distance from the eye, as to give the rays flowing from it the degrees of convergence represented in the figure, and suppose that the rays enter the eye under such an angle as to make the object appear two feet in length. 2. Now, the length of the same object, seen through the concave lens, Fig. 189, will appear diminished, because the rays coming from it are bent outwards, or made less convergent by refraction, as seen in the figure, and consequently the visual angle is more acute than when the same object is seen by the naked eye. Its length, therefore, will appear less, in proportion as the rays are rendered less convergent.

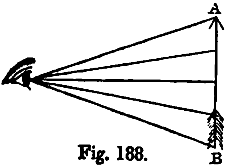


Fig. 188.

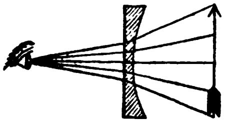


Fig. 189.

473. "The spectacle glasses of short-sighted people are concave lenses, by which the images of objects are formed further back in the eye than otherwise, as will be explained under the next article.

VISION.

474. "In the application of the principles of optics to the explanation of natural phenomena, it is necessary to give a description of the most perfect of all optical instruments, the eye. Fig. 190 is a vertical section of the human eye. Its form is nearly globular, with a slight projection or elongation in front. It consists of four coats, or membranes; name-

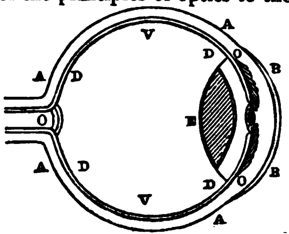


Fig. 190.

ly, the *sclerotic*, the *cornea*, the *choroid*, and the *retina*. It has two fluids confined within these membranes, called the *aqueous*, and the *vitreous* humours; and one lens, called the *crystalline*. The sclerotic coat is the outer and strongest membrane, and its anterior part is well known as the *white* of the eye. This coat is marked in the figure A, A, A, A. It is joined to the cornea, B, B, which is the transparent membrane in front of the eye, through which we see. The choroid coat is a thin, delicate membrane, which lines the sclerotic coat on the inside. On the inside of this lies the *retina*, D, D, D, D, which is the innermost coat of all, and is an expansion, or continuation, of the optic nerve O. This expansion of the optic nerve is the immediate seat of vision. The iris, O, O, is seen through the cornea, and is a thin membrane, or curtain, of different colours in different persons, and therefore gives colour to the eyes. In black eyed persons it is black, in blue eyed persons it is blue, &c. Through the iris, is a circular opening, called the *pupil*, which expands or enlarges when the light is faint, and contracts when it is too strong. The space between the iris and the cornea is called the *anterior chamber* of the eye, and is filled with the *aqueous* humour, so called from its resemblance to water. Behind the pupil and iris is situated the crystalline lens E, which is a firm and perfectly transparent body, through which the rays of light pass from the pupil to the retina. Behind the lens is situated the *posterior chamber* of the eye, which is filled with the *vitreous humour*, V, V. This humour occupies much the larger portion of the whole eye, and on it depends the shape and permanency of the organ.

475. "From the above description of the eye, it will be easy to trace the progress of the rays of light through its several parts, and to explain in what manner vision is performed. In doing this, we must keep in mind that the rays of light proceed from every part and point of a visible object, as heretofore stated, and that it is necessary only for a few of the rays, when compared with the whole number, to enter the eye, in order to make the object visible. Thus, the object A B, Fig. 191, being placed in the

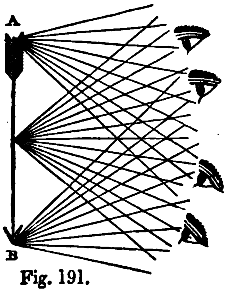


Fig. 191.

light, sends forth pencils of rays in all possible directions, some of which will strike the eye in any position where it is visible. These pencils of rays not only flow from the points designated in the figure, but in the same manner from every other point on the surface of a visible object. To render an object visible, therefore, it is only necessary that the eye should collect and concentrate a sufficient number of these rays on the retina, to form its image there, and from this image the sensation of vision is excited.

476. "From the luminous body L, Fig. 192, the pencils of rays flow in all directions, but it is only by those which enter the pupil, that we gain any knowledge of its existence; and even these would convey to the mind no distinct idea of the object, unless they were refracted by the humours of the eye, for, if these rays proceeded in their natural state of divergence to the retina, the image there formed would be too extensive, and consequently too feeble to give a distinct sensation of the object. It is, therefore, by the refracting power of the aqueous humour, and of the crystalline lens, that the pencils of rays are so concentrated as to form a perfect picture of the object on the retina.

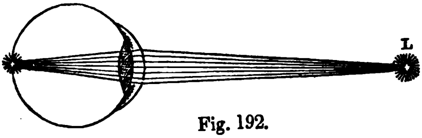


Fig. 192.

477. "We have already seen, that when the rays of light are made to cross each other by reflection from the concave mirror, the image of the object is inverted; the same thing happens when the rays are made to cross each other by refraction through a convex lens. This, indeed, must be a necessary consequence of the intersection of the rays; for, as light proceeds in straight lines, those rays which come from the lower part of an object, on crossing those which come from its upper part, will represent this part of the picture on the upper half of the retina, and for the same reason, the upper part of the object will be painted on the lower part of the retina.

478. "Now, all objects are represented on the retina in an inverted position; that is, what we call the upper end of a vertical object, is the lower end of its picture on the retina,

and so the contrary. This is readily proved by taking the eye of an ox, and cutting away the sclerotic coat, so as to make it transparent on the back part, next the vitreous humour. If now a piece of white paper be placed on this part of the eye, the images of objects will appear figured on the paper in an inverted position. The same effect will be produced on looking at objects through an eye thus prepared; they will appear inverted. The actual position of the vertical object A, Fig. 193, as painted on the retina, is therefore such as is represented by the figure. The rays from its upper extremity, coming in divergent lines, are converged by the crystalline lens, and fall on the retina at O; while those from its lower extremity, by the same law, fall on the retina at C.

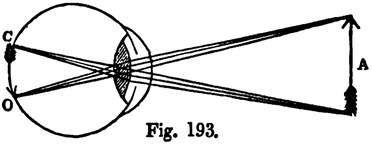


Fig. 193.

479. "In order that vision may be perfect, it is necessary that the images of objects should be formed precisely on the retina, and consequently, if the refractive power of the eye be too small, or too great, the image will not fall exactly on the seat of vision, but will be formed either before, or tend to be formed behind it. In both cases, perhaps, an outline of the object may be visible, but it will be confused and indistinct.

480. "If the cornea is too convex, or prominent, the image will be formed before it reaches the retina, for the same reason, that of two lenses, that which is the more convex will have the less focal distance. Such is the defect in the eyes of persons who are shortsighted, and hence the necessity of their bringing objects as near the eye as possible, so as to make the rays converge at the greatest distance behind the

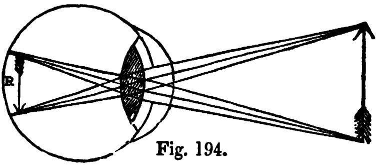


Fig. 194.

crystalline lens. The effect of uncommon convexity in the cornea on the rays of light, is shown at Fig. 194, where it will be observed that the image, instead of being formed on the retina R, is suspended in the vitreous humour, in consequence of there being too great a refractive power in the eye. It is hardly necessary to say, that in this case, vision must be very imperfectly performed. This defect of sight, termed *short-sightedness*, is remedied by spectacles, the glasses of which are concave lenses. Such glasses, by rendering the rays of light less convergent, before they reach the eye, counteract the too great convergent power of the cornea and lens, and thus throw the image on the retina.

481. "If, on the contrary, the humours of the eye, in consequence of age, or any other cause, have become less in quantity than ordinary, the eyeball will not be sufficiently distended, and the cornea will become too flat, or not sufficiently convex, to make the rays of light meet at the proper place, and the image will therefore tend to be formed beyond the retina, instead of before it, as in the other case. Hence, aged people, who labour under this defect of vision, cannot see distinctly at ordinary distances, but are obliged to remove the object as far from the eye as possible, so as to make its refractive power bring the image within the seat of vision. The defect arising from this cause is represented by Fig. 195, where it will be observed that the image is formed behind the retina, showing that the convexity of the cornea is not sufficient to bring the image within the seat of distinct vision. This imperfection of sight is common to aged persons, and is corrected in a greater or less degree by double convex lenses, such as the common spectacle glasses. Such glasses, by causing the rays of light to converge, before they meet the eye, assist the refractive power of the crystalline lens, and thus bring the focus, or image, within the sphere of vision.

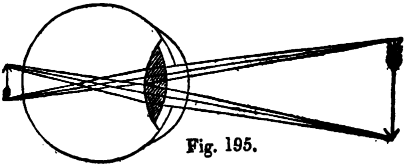


Fig. 195.

482. "It has been considered difficult to account for the

reason why we see objects erect, when they are painted on the retina inverted, and many learned theories have been written to explain this fact. But it is most probable that this is owing to habit, and that the image, at the bottom of the eye, has no relation to the terms above and below, but to the position of our bodies, and other things which surround us. The term *perpendicular*, and the idea which it conveys to the mind, are merely relative; but when applied to an object supported by the earth, and extending towards the skies, we call the body erect, because it coincides with the position of our own bodies, and we see it erect for the same reason. Had we been taught to read by turning our books upside down, what we now call the upper part of the book would have been its under part, and that reading would have been as easy in that position as in any other, is plain from the fact that printers read their types, when set up, as readily as they do their impressions on paper.

483. "*Angle of vision.*—The angle of vision, or that angle under which the rays of light, coming from the extremities of an object, cross each other at the eye, bears a proportion directly to the length, and inversely to the distance of the object. Suppose the object A B, Fig. 196, to be four feet long, and to be placed ten feet from the eye, then the rays flowing from its extremities, would intersect each other at the eye, under a given angle, which will always be the same when the object is at the same distance. If the object be gradually moved towards the eye, to the place C D, then the angle will be gradually increased in quantity, and the object will appear larger, since its image on the retina will be increased in length in the proportion as the lines I I are wider apart than O O. On the contrary, were A B removed to a greater distance from the first position, it is obvious that the angle would be diminished in proportion. The lines thus proceeding from the extremities of an object, and represent-

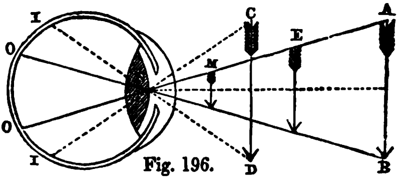


Fig. 196.

ing the rays of light, form an angle at the eye, which is called the *visual angle*, or the angle under which things are seen. These lines A N B, therefore, form one visual angle, and the lines C N D another visual angle.

484. "We see from this investigation, that the apparent magnitude of objects depending on the angles of vision, will vary according to their distances from the eye, and that these magnitudes diminish in a proportion inversely as their distances increase. We learn, also, from the same principles that objects of different magnitudes may be so placed, with respect to the eye, as to give the same visual angle, and thus to make their apparent magnitudes equal. Thus the three arrows, A, E, and M, though differing so much in length, are all seen under the same visual angle.

485. "In the apparent magnitude of objects seen through a lens, or when their images reach the eye by reflection from a mirror, our senses are chiefly, if not entirely, guided by the angle of vision. In forming our judgment of the sizes of distant objects, whose magnitudes were before unknown, we are also guided more or less by the visual angle, though in this case we do not depend entirely on the sense of vision. Thus, if we see two balloons floating in the air, one of which is larger than the other, we judge of their comparative magnitudes by the difference in their visual angles, and of their real magnitudes by the same angles, and the distance we suppose them to be from us.

486. "But when the object is near us, and seen with the naked eye, we then judge of the magnitude by our experience, and not entirely by the visual angle. Thus, the three arrows, A, E, M, Fig. 196, all of them make the same angle on the eye, and yet we know, by further examination, that they are all of different lengths. And so the two arrows A B, and C D, though seen under different visual angles, will appear of the same size, because experience has taught us that this difference depends only on the comparative distance of the two objects.

487. "As the visual angle diminishes inversely in proportion as the distance of the object increases, so when the distance is so great as to make the angle too minute to be perceptible to the eye, then the object becomes invisible. Thus, when we watch an eagle, flying from us, the angle of vision is gradually diminished, until the rays proceeding from the bird form an image on the retina too small to excite sensa-

tion, and then we say the eagle has flown out of sight. The same principle holds with respect to objects which are near the eye, but are too small to form an image on the retina which is perceptible to the senses. Such objects, to the naked eye, are of course invisible, but when the visual angle is enlarged by means of a convex lens, they become visible; that is, their images on the retina excite sensation.

488. "The actual size of an image on the retina, capable of exciting sensation, and consequently of producing vision, may be too small for us to appreciate by any of our other senses; for when we consider how much smaller the image must be than the object, and that a human hair can be distinguished by the naked eye at the distance of twenty or thirty feet, we must suppose that the retina is endowed with the most delicate sensibility, to be excited by a cause so minute. It has been estimated that the image of a man, on the retina, seen at the distance of a mile, is not more than the five-thousandth part of an inch in length.

489. "On the contrary, if the object be brought too near the eye, its image becomes confused and indistinct, because the rays flowing from it fall on the crystalline lens in a state too divergent to be refracted to a focus on the retina. This will be apparent by Fig. 197, where we suppose that the object, A, is brought within an inch or two of the eye, and that the rays proceeding from it enter the pupil so obliquely as not to be refracted by the lens, so as to form a distinct image.

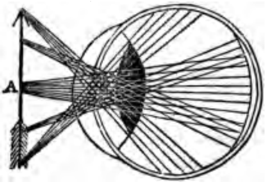


Fig. 197.

490. "Could we see objects distinctly at the shortest distance, we should be able to examine things that are now invisible, since the visual angle would then be increased, and consequently the image on the retina enlarged, in proportion as objects were brought near the eye. This is proved by intercepting the most divergent rays; in which case an object may be brought near the eye, and will then appear greatly magnified. Make a small orifice, as a pinhole, through a piece of dark-coloured paper, and then look through the orifice at small objects, such as the letters of a printed book. The letters will appear much magnified. The rays in this case are refracted to a focus on the retina,

because the small orifice prevents those which are most divergent from entering the eye, so that notwithstanding the nearness of the object, the rays which form the image are nearly parallel.

OPTICAL INSTRUMENTS.

491. "*Single microscope.*—The principle of the single microscope, or convex lens, will be readily understood, if the pupil will remember what has been said on the refraction of lenses, in connection with the facts just stated. For, the reason why objects appear magnified through a convex lens, is not only because the visual angle is increased, but because when brought near the eye, the diverging rays from the object are rendered parallel by the lens, and are thus thrown into a condition to be brought to a focus in the proper place by the humours. Let A, Fig. 198, be the distance at which an object can be seen distinctly, and B the distance at which the same object is seen through the lens, and suppose the distance of A, from the eye, be twice that of B. Then, because the object is at half the distance that it was before, it will appear twice as large; and had it been seen one-third, one-fourth, or one-tenth its former distance, it would have been magnified three, four, or ten times, and consequently its surface would be increased 9, 16, or 100 times.

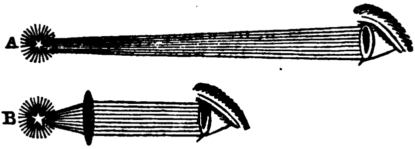


Fig. 198.

492. "The most powerful single microscopes are made of minute globules of glass, which are formed by melting the ends of a few threads of spun glass in a candle. Small globules of water placed in an orifice through a piece of tin, or other thin substance, will also make very powerful microscopes. In these minute lenses, the focal distance is only a tenth or twelfth part of an inch from the lens, and therefore the eye, as well as the object to be magnified, must be brought very near the instrument.

493. "The *compound microscope* consists of two convex lenses, by one of which the image is formed within the tube

of the instrument, and by the other this image is magnified, as seen by the eye; so that by this instrument the object itself is not seen, as with the single microscope, but we see only its magnified image. The small lens placed near the object, and by which its image is formed within the tube, is called the *object glass*, while the larger one, through which the image is seen, is called the *eye glass*.

494. "This arrangement is represented at Fig. 199. The object A is placed a little beyond the focus of the object glass B, by which an inverted and enlarged image of it is formed within the instrument at C. This image is seen through the eye glass D, by which it is again magnified, and it is at last figured on the retina in its original position. These glasses are set in a case of brass, the object glass being made to take out, so that others of different magnifying powers may be used, as occasion requires.

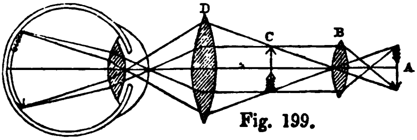


Fig. 199.

495. "The *solar microscope* consists of two lenses, one of which is called the *condenser*, because it is employed to concentrate the rays of the sun, in order to illuminate more strongly the object to be magnified. The other is a double convex lens, of considerable magnifying power, by which the image is formed. In addition to these lenses, there is a plain mirror, or piece of common looking glass, which can be moved in any direction, and which reflects the rays of the sun on the condenser. The object A, Fig. 200, being placed nearly in the focus of the condenser B, is strongly illuminated, in consequence of the rays of the sun being thrown on B, by the mirror C. The object is not placed exactly in the focus

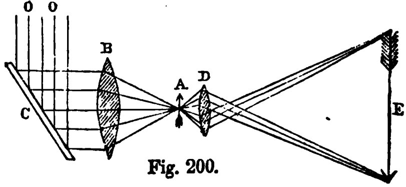


Fig. 200.

of the condenser, because, in most cases, it would be soon destroyed by its heat, and because the focal point would illuminate only a small extent of surface, but may be exactly in the focus of the small lens D, by which no such accident can happen. The lines O O, represent the incident rays of the sun, which are reflected on the condenser.

496. "When the solar microscope is used, the room is darkened, the only light admitted being that which is thrown on the object by the condenser, which light passing through the small lens, gives the magnified shadow E, of the small object A, on the wall of the room, or on a screen. The tube containing the two lenses is passed through the window of the room, the reflector remaining outside. In the ordinary use of this instrument, the object itself is not seen, but only its shadow on the screen, and it is not designed for the examination of opaque objects.

497. "When the small lens of the solar microscope is of great magnifying power, it presents some of the most striking and curious of optical phenomena. The shadows of mites from cheese or figs, appear nearly two feet in length, presenting an appearance exceedingly formidable and disgusting; and the insects from common vinegar appear eight or ten feet long, and in perpetual motion, resembling so many huge serpents.

TELESCOPE.

498. "The *telescope* is an optical instrument, employed to view distant bodies, and, in effect, to bring them nearer the eye, by increasing the apparent angles under which such objects are seen. These instruments are of two kinds, namely, *refracting* and *reflecting* telescopes. In the first kind, the image of the object is seen with the eye directed towards it; in the second kind, the image is seen by reflection from the mirror, while the back is towards the object, or by a double reflection, with the face toward the object.

499. "The telescope is the most important of all optical instruments, since it unfolds the wonders of other worlds, and gives us the means of calculating the distances of the heavenly bodies, and of explaining their phenomena for astronomical and nautical purposes.* The principle of the

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* It has been proposed by Dr Marshall Hall, to employ the *adjustment* of the telescope as a measurer of distances, and, as a consequence, of the heights of mountains, &c.

telescope will be readily comprehended after what has been said concerning the compound microscope, for the two instruments differ chiefly in respect to the place of the object lens, that of the microscope having a short, while that of the telescope has a long, focal distance.

500. "REFRACTING TELESCOPE.—The most simple refracting telescope consists of a tube, containing two convex lenses, the one having a long, and the other a short, focal distance. (The focal distance of a double convex lens, it will be remembered, is nearly the centre of a sphere, of which it is a part.) These two lenses are placed in the tube, at a distance from each other equal to the sum of their two focal distances. Thus, if the focus of the object glass A, Fig. 201, be eight inches, and that of the eye glass B, two inches, then the distance of the sums of the foci will be ten inches, and, therefore, the two lenses must be placed ten inches apart; and the same rule is observed, whatever may be the focal lengths of any two lenses. Now, to understand the effect of this arrangement, suppose the rays of light, C D, coming from a distant object, as a star, to fall on the object glass A, in parallel lines, and to be refracted by the lens to a focus at E, where the image of the star will be represented. This image is then magnified by the eye glass B, and thus, in effect, is brought near the eye. All that is effected by the telescope, therefore, is to form an image of a distant object, by means of the object lens, and then to assist the eye in viewing this image as nearly as possible by the eye lens.

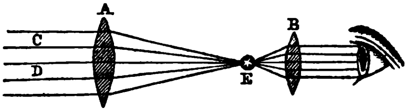

Fig. 201.

501. "It is, however, necessary here to state, that by the last figure, the principle only of the telescope is intended to be explained, for in the common instrument, with only two glasses, the image appears to the eye inverted. The reason of this will be seen by the next figure, where the direction of the rays of light will show the position of the image. Suppose A, Fig. 202, to be a distinct object, from which pencils of rays flow from every point toward the object lens B. The image of A, in consequence of the refraction of the rays by

the object lens, is inverted at C, which is the focus of the eye glass D, and through which the image is then seen, still inverted.

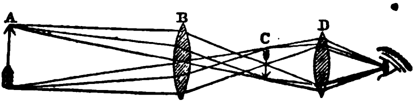

Fig. 202.

502. "The inversion of the object is of little consequence when the instrument is employed for astronomical purposes, for since the forms of the heavenly bodies are spherical, their positions, in this respect, do not affect their general appearance. But for terrestrial purposes, this is manifestly a great defect, and therefore those constructed for such purposes as ship, or spy glasses, have two additional lenses, by means of which, the images are made to appear in the same position as the objects. These are called *double telescopes.*

503. "Such a telescope is represented at Fig. 203, and consists of an object glass A, and three eye glasses, B, C, and D. The eye glasses are placed at equal distances from each other, so that the focus of one may meet that of the other, and thus the image formed by the object lens will be transmitted through the other three lenses to the eye. The rays coming from the object O, cross each other at the focus of the object lens, and thus form an inverted image at F. This image being also in the focus of the first eye glass, B, the rays having passed through this glass, become parallel, for, we have seen in another place, that diverging rays are rendered parallel by refraction through a convex lens. The rays, therefore, pass parallel to the next lens C, by which they are made to converge, and cross each other, and thus the image is inverted, and made to assume the original position of the object O. Lastly, this image, being in the focus of the eye glass D, is seen in the natural position, or in that of the object. The apparent magnitude of the object is not

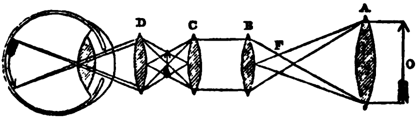

Fig. 203.

[illegible] glasses, but depends, as in [illegible] of the eye and object [illegible] merely for the purpose [illegible]

[illegible] of very high magnify- [illegible] refracting telescope, [illegible] that the image be- [illegible] formerly made [illegible] among these it was [illegible] of the object lens [illegible] was attended with great [illegible] of the length of [illegible] These experiments were, [illegible] refracting telescope itself [illegible] in consequence [illegible]

[illegible] —The common reflecting [illegible] concave re- [illegible] glasses. The [illegible] the small [illegible] the two eye glasses, [illegible] advantages of the [illegible] that the refracting [illegible] feet, if it could [illegible] more than a thousand times, while a reflecting telescope, only eight or nine feet long, will magnify with distinctness twelve hundred times.

[illegible] The principle and construction [illegible] the reflectin[illegible] telescope will be understood by Fig [illegible] Suppose [illegible]

[illegible]

concave, they are thrown back in nearly parallel lines, and having passed the aperture in the centre of the great mirror, fall on the plano-convex lens E. By this lens they are refracted to a focus, and cross each other between E and D, and thus the image is again inverted, and brought to its original position, or in the position of the object. The rays then, passing the second eye glass, form the image of the object on the retina. The large mirror in this instrument is fixed, but the small one moves backwards and forwards, by means of a screw, so as to adjust the image to the eyes of different persons. Both mirrors are made of a composition, consisting of several metals melted together.

507. “One great advantage which the reflecting telescope possesses over the refracting, appears to be, that it admits of an eye glass of shorter focal distance, and, consequently, of greater magnifying power. The convex object glass of the refracting instrument does not form a perfect image of the object, since some of the rays are dispersed, and others coloured by refraction. This difficulty does not occur in the reflected image from the metallic mirror of the reflecting telescope, and consequently it may be distinctly seen when more highly magnified. The instrument just described is called “*Gregory's telescope*,” because some parts of the arrangement were invented by Dr Gregory.

508. “In the telescope made by Dr Herschel, the object is reflected by a mirror, as in that of Dr Gregory. But the sec[illegible] small reflector, is not employed, the image being s[illegible]h a convex lens, placed so as to magnify the [illegible] large mirror, so that the observer stands with [illegible]rds the object. The magnifying power of this [illegible] the same as that of Dr Gregory's, but the image [illegible]ter, because there is no second reflection; for [illegible]n renders the image fainter, since no mirror is [illegible]o throw back all the rays which fall upon its sur[illegible] Hers[illegible]rand telescope, the largest ever con[illegible] re[illegible] 48 inches in diameter, and had a [illegible] This reflector was three and a half [illegible] 2000 pounds. Now, since the [illegible] at the distance of one half the [illegible] of which it is a section, Dr [illegible] focal distance of 40 feet, formed [illegible] in diameter. This great instru[illegible] finished four years afterwards.

The frame, by which this wonder to all astronomers was supported, having decayed, it was taken down in 1822, and another of 20 feet focus, with a reflector of 18 inches in diameter, erected in its place, by Herschel's son. The largest Herschel's telescope now in existence is that of Greenwich observatory, in England. This has a concave reflector of 15 inches in diameter, with a focal length of 25 feet, and was erected in 1820.

509. "CAMERA OBSCURA.—The term *camera obscura* strictly signifies a darkened chamber, because the room must be darkened, in order to observe its effects. To witness the phenomena of this instrument, let a room be closed in every direction, so as to exclude the light. Then from an aperture, say of an inch in diameter, admit a single beam of light, and the images of external things, such as trees, and houses, and persons walking the streets, will be seen inverted on the wall opposite to where the light is admitted, or on a screen of white paper, placed before the aperture. The reason why the image is inverted, will be obvious, when it is remembered that the rays proceeding from the extremities of the object must converge in order to pass through the small aperture; and as the rays of light always proceed in straight lines, they must cross each other at the point of admission, as explained under the article *Vision.* Thus, the pencil A, Fig. 205, coming from the upper part of the tower, and proceeding straight, will represent the image of that part at B, while the lower part C, for the same reason will be represented at D. If a convex lens, with a short tube, be placed in the aperture through which the light passes into the room, the images of things will be much more perfect, and their colours more brilliant. This instrument is sometimes employed by painters, in order to obtain an exact delineation of a landscape, an outline of the image being easily taken with a pencil, when the image is thrown on a sheet of paper.

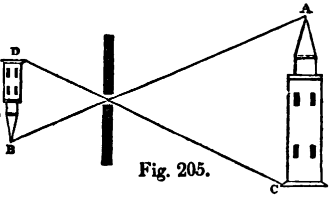

Fig. 205.

510. "There are several modifications of this machine, and among them the *revolving* camera obscura is the most interesting. It consists of a small house, Fig. 206, with a plane reflector, A B, and a convex lens, C B, placed at its top. The

reflector is fixed at an angle of 45 degrees with the horizon, so as to reflect the rays of light perpendicularly downwards, and is made to revolve quite around, in either direction, by pulling a string. Now suppose the small house to be placed in the open air, with the mirror, A B, turned towards the east, then the rays of light flowing from the objects in that direction, will strike the mirror in the direction of the lines D, and be reflected down through the convex lens C B, to the table E E, where they will form in miniature a most perfect and beautiful picture of the landscape in that direction. Then, by making the reflector revolve, another portion of the landscape may be seen, and thus the objects, in all directions, can be viewed at K without changing the place of the instrument.

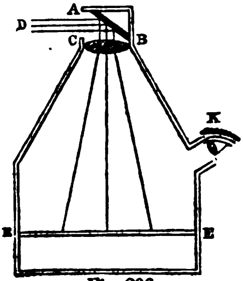

Fig. 206.

511. "MAGIC LANTERN.—The magic lantern is a microscope, on the same principle as the solar microscope. But instead of being used to magnify natural objects, it is commonly employed for amusement, by the casting shadows of small transparent paintings, done on glass, upon a screen placed at a proper distance. Let a candle C, Fig. 207, be placed on the inside of a box, or tube, so that its light may pass through the plano-convex lens N, and strongly illuminate the object O. This object is generally a small transparent painting on a slip of glass, which slides through an opening in the tube. In order to show the figures in the erect position, these paintings are inverted, since their shadows are again inverted by the refraction of the convex lens M. In some of these instruments, there is a concave mirror, D, by which the object, O, is more strongly illumi-

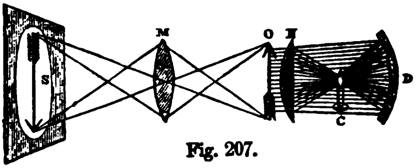

Fig. 207.

nated than it would be by the lamp alone. The object is magnified by the double convex lens, M, which is moveable in the tube by a screw, so that its focus can be adjusted to the required distance. Lastly, there is a screen of white cloth, placed at the proper distance, on which the image, or shadow of the picture, is seen greatly magnified. The pictures being of various colours, and so transparent that the light of the lamp shines through them, the shadows are also of various colours, and thus soldiers and horsemen are represented in their proper costume.

CHROMATICS, OR THE PHILOSOPHY OF COLOURS.

512. "We have thus far considered light as a *simple* substance, and have supposed that all its parts were equally refracted in its passage through the several lenses described. But it will now be shown that light is a *compound* body, and that each of its rays, which to us appear white, is composed of several colours, and that each colour suffers a different degree of refraction, when the rays of light pass through a piece of glass of a certain shape."

513. *Decomposition of light.*—It is found that a ray of light may be *decomposed*, or separated into its constituent parts, or rays. If a ray of light from the sun S be admitted into a dark room through an aperture in a window shutter H, and be made to pass through a solid angle of glass, or *prism*, A, instead of passing onward in its natural direction C, it is refracted as it enters the glass, and is again refracted as it passes out of it. If it be now received upon a white card, M N, it will be found to have been decomposed, and instead of presenting a round spot of white light, it exhibits an oblong

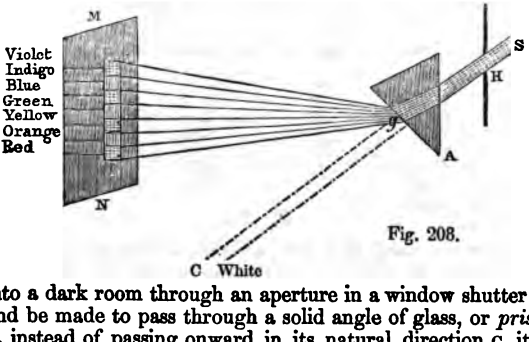

Fig. 208.

image, consisting of *seven* bands of different colours, which will be situated in respect to each other as named in the figure. This oblong image is called the *solar*, or *prismatic spectrum*. When the rays of light which have been thus separated, are collected again by a lens, white or common light is produced. The separation of the beams of light composing the spectrum is owing to their having different refractive powers, the red being refracted in the least, the violet in the greatest degree, from their original direction C. Each of the seven colours consists of light which is no longer decomposable, like common light, but has uniform refractive properties; and, hence, they were termed by Newton, simple or *homogeneous* colours, to distinguish them from common or white light, which he called compound or *heterogeneous*.

514. The coloured bands of the spectrum differ in width, and are shaded into each other; and it has been recently determined by Sir D. Brewster that the *primary* rays of colour are *three* only, blue, yellow, and red, the others being merely compositions of these. A portion of each of the primary rays is found at every point of the spectrum, together with a certain quantity of white light; but each of the primary rays predominates at a particular point of the spectrum. The blue rays are near the top, and are the most refrangible; the yellow are somewhat below the middle, and are less refrangible; the red occupy the lowest part, and are least refrangible. The *compound spectrum* is produced by the combination of the three simple spectra, the blue, the yellow, and the red, which are shaded as represented in the figure. Hence, not one of the seven colours of Newton is pure, the orange being produced by predominance of the yellow and red rays; the green, by the yellow and blue rays; while the indigo and violet are essentially blue, with different proportions of red and yellow. Upon these laws depend the endless variety and change of colours: bodies appear to have a particular colour, according as they are enabled to reflect or transmit the rays of some colours,

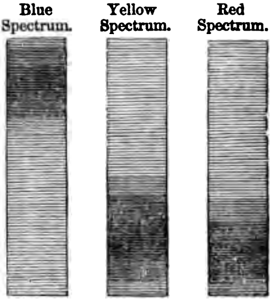

Fig. 209.

and to absorb or reflect the rest; while white bodies reflect all, and black bodies absorb all.

515. "The prism is not the only instrument by which light can be decomposed. 1. A soap bubble blown up in the sun will display most of the prismatic colours. This is accounted for by supposing that the sides of the bubble vary in thickness, and that the rays of light are decomposed by these variations. 2. The unequal surface of *mother of pearl*, and many other shells, send forth coloured rays on the same principle. 3. Two surfaces of polished glass, when pressed together, will also decompose the light. Rings of coloured light will be observed around the point of contact between the two surfaces, and their number may be increased or diminished by the degrees of pressure. 4. Two pieces of common looking glass, pressed together with the fingers, will display most of the prismatic colours. 5. A variety of substances, when thrown into the form of the triangular prism, will decompose the rays of light, as well as a prism of glass. A very common instrument for this purpose is made by putting together three pieces of plate glass, in form of a prism. The ends may be made of wood, and the edges cemented with putty, so as to make the whole water tight. When this is filled with water, and held before a sunbeam, the solar spectrum may be formed, displaying the same colours, and in the same order as that above described.

516. "In making experiments with prisms filled with different kinds of liquids, it has been found that one liquid will make the spectrum longer than another; that is, the red and violet rays, which form the extremes of the spectrum, will be thrown farther apart by one fluid than by another. For example, if the prism be filled with oil of cassia, the spectrum formed by it will be more than twice as long as that formed by a prism of solid glass. The oil of cassia is therefore said to disperse the rays of light more than glass, and hence to have a greater *dispersive power*.

517. "THE RAINBOW.—The rainbow was a phenomenon for which the ancients were entirely unable to account; but after the discovery that light is a compound principle, and that its colours may be separated by various substances, the solution of this phenomenon became easy. Sir Isaac Newton, after his great discovery of the compound nature of light, and the different refrangibility of the coloured rays, was able to explain the rainbow on optical principles.

518. "If a glass globe be suspended in a room, where the rays of the sun can fall upon it, the light will be decomposed, or separated into several coloured rays, in the same manner as is done by the prism. A well defined spectrum will not, however, be formed by the globe, because its shape is such as to disperse some of the rays, and converge others; but the eye, by taking different positions in respect to the globe, will observe the various prismatic colours. Transparent bodies, such as glass and water, reflect the rays of light from both their surfaces, but chiefly from the second surface. That is, if a plate of naked glass be placed so as to reflect the image of the sun, or of a lamp, to the eye, the most distinct image will come from the second surface, or that most distant from the eye. The great brilliancy of the diamond is owing to this cause. It will be understood directly, how this principle applies to the explanation of the rainbow.

519. "Suppose the circle A B C, Fig. 210, to represent a globe, or a drop of rain, for each drop of rain, as it falls through the air, is a small globe of water. Suppose, also, that the sun is at S, and the eye of the spectator at E. Now, it has already been stated, that from a single globe, the whole solar spectrum is not seen in the same position, but that the different colours are seen from different places. Suppose, then, that a ray of light from the sun S, on entering the globe at A, is separated into its primary colours, and at the same time the red ray, which is the least refrangible, is refracted in the line from A to B. From the second, or inner surface of the globe, it would be reflected to C, the angle of reflection being equal to that of incidence. On passing out of the globe, its refraction at C, would be just equal to the refraction of the incident ray at A, and therefore the red ray would fall on the eye at E. All the other coloured rays would follow the same law,

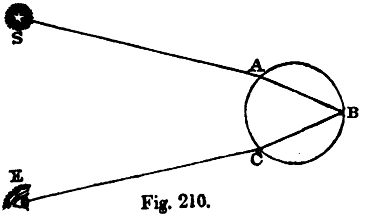

Fig. 210.

but because the angles of incidence and those of reflection are equal, and because the coloured rays are separated from each other by unequal refraction, it is obvious, that if the red ray entered the eye at E, none of the other coloured rays could be seen from the same point.

520. "From this it is evident, that if the eye of the spectator is moved to another position, he will not see the red ray coming from the same drop of rain, but only the blue, and if to another position, the green, and so of all the others. But in a shower of rain, there are drops at all heights and distances, and though they perpetually change their places, in respect to the sun and the eye, as they fall, still there will be many which will be in such a position as to reflect the red rays to the eye, and as many more to reflect the yellow rays, and so of all the other colours.

521. "This will be made obvious by Fig. 211, where, to avoid confusion, we will suppose that only three drops of rain, and, consequently, only three colours, are to be seen. The numbers 1, 2, 3, are the rays of the sun, proceeding to the drops A, B, C, and from which these rays are reflected to the eye, making different angles with the horizontal line H, because one coloured ray is refracted more than another. Now, suppose the red ray only reaches the eye from the drop A, the green from the drop B, and the violet from the drop C, then the spectator would see a minute rainbow of three colours. But during a shower of rain, all the drops which are in the position of A, in respect to the eye, would send forth red rays, and no other, while those in the position of B, would emit green rays, and no other, and those in the position of C, violet rays, and so of all the other prismatic colours. Each circle of colours, of which the rainbow is formed, is therefore composed of reflections from a vast number of different drops of rain, and the reason why these colours are distinct to our senses, is, that we see only one colour from a single

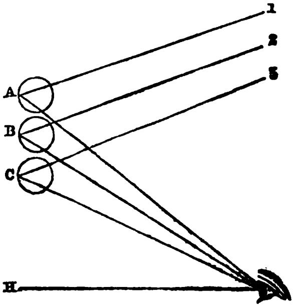

Fig. 211.

drop, with the eye in the same position. It follows, then, that if we change our position, while looking at a rainbow, we still see a bow, but not the same as before, and hence, if there are many spectators, they will all see a different rainbow, though it appears to be the same.

522. "There are often seen two rainbows, the one formed as above described, and the other, which is fainter, appearing on the outside, or above this. The secondary bow, as this last is called, always has its order of colours the reverse of the primary one. Thus, the colours of the primary bow, beginning with its upper, or outermost portion, are red, orange, yellow, &c., the lowest, or innermost portion, being violet; while the secondary bow, beginning with the same corresponding parts, is coloured violet, indigo, &c., the lowest, or innermost circle, being red.

523. "In the primary bow, we have seen, that the coloured rays arrive at the eye after two refractions, and one reflection. In the secondary bow, the rays reach the eye after two refractions, and two reflections, and the order of the colours is reversed, because, in this case, the rays of light enter the lower part of the drop, instead of the upper part, as in the primary bow. The reason why the colours are fainter in the secondary than in the primary bow is, because a part of the light is lost or dispersed, at each reflection; and there being two reflections, by which this bow is formed, instead of one, as in the primary, the difference in brilliancy is very obvious.

524. "The direction of a single ray, showing how the secondary bow is formed, will be seen at Fig. 212. The ray

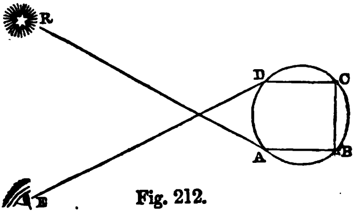

Fig. 212.

R, from the sun, enters the drop of water at A, and is *refracted* to B, then *reflected* to C, then again reflected to D, where it suffers another refraction, and lastly, passes to the eye of the spectator at E.

525. "The rainbow, being the consequence of the refracted and reflected rays of the sun, is never seen, except when the sun and the spectator are in similar directions, in respect to the shower. It assumes the form of a semicircle, because it is only at certain angles that the refracted rays are visible to the eye." The size of the bow depends upon the height of the sun above the horizon. When the sun is in the horizon, the bow will be a semicircle to a spectator on a plane; but on the summit of a mountain, he may see a segment greater than a semicircle.

526. *Lunar rainbow; halo; parhelion.*—Besides the solar rainbow, above described, many peculiar kinds of rainbow have been observed. 1. A *lunar rainbow* is of rare occurrence, but its colours differ little, except in intensity, from those of the common rainbow. Mr Thoresby describes a phenomenon of this kind, which occurred when the moon had passed her full about twenty-four hours; it had all the colours of the solar iris, only faint in comparison with those observed in the day. The arc was remarkable for its size, being not so much less than that of the sun, as the different dimensions of these bodies, and their respective distances from the earth, seem to require. (*Phil. Trans.* 1711). 2. In the highest northern latitudes, where the air is commonly loaded with frozen particles, the sun and moon usually appear surrounded by *halos*, or coloured circles, at the distances of about twenty-two and forty-six degrees from their centres; this appearance is also frequently observed in other climates, especially in the colder months, and in the light clouds which float in the highest regions of the air. The halos are usually attended by a horizontal white circle, with brighter spots, or *parhelia*, near their intersection with this circle, and with portions of inverted arches of various curvatures; the horizontal circle has also sometimes *anthelia*, or bright spots, nearly opposite to the sun.

527. Various explanations of these phenomena have been offered. The following is, however, the most simple and obvious. The natural tendency of water to crystallize, in freezing, at an angle of sixty degrees, is sufficiently established, to allow us to assume this as the constant angle of the elementary crystals of snow, which are probably either triangular or hexagonal prisms. The deviation produced by such a prism differs very little from the observed angle at which the first circle is usually seen; and all the principal phenomena,

which attend this circle may be explained, by supposing the axis of the crystals to assume a vertical or a horizontal position, in consequence of the operation of gravity. Thus, the *parhelia*, which are sometimes a little more distant from the sun than the halo, are attributed by Mariotte to the refraction of the prisms which are situated vertically, and produce a greater deviation, on account of the obliquity of the rays of light with respect to their axis. The horizontal circle may be deduced from the reflection, or even the repeated refractions, of the vertical facets; the anthelia from two refractions with an intermediate reflection; and the inverted arch, from the increase of the deviation, in the light passing obliquely through prisms lying in a horizontal position. The external circle may be attributed either to two successive refractions through different prisms; or, with greater probability, as Mr Cavendish suggested, to the effect of the rectangular terminations of the single crystals. The appearance of colours in halos, is nearly the same as in rainbows, but less distinct; the red being nearest to the luminary, and the whole halo being externally very ill defined. (Young, Nat. Phil. vol. i.)

528. Supernumerary rainbows are sometimes seen. "On the 5th of July, 1828," says Sir D. Brewster, "I observed three supernumerary bows within the primary bow, each consisting of green and red arches, and in contact with the violet arch of the primary bow. On the outside of the outer or secondary bow, I saw distinctly a red arch, and beyond it a very faint green one, constituting a supernumerary bow, analogous to those within the primary rainbow."

529. "*Of the colours of objects.*—The light of the sun, we have seen, may be separated into seven primary rays, each of which has a colour of its own, and which is different from that of the others. In the objects which surround us, both natural and artificial, we observe a great variety of colours, which differ from those composing the solar spectrum, and hence one might be led to believe that both nature and art afford colours different from those afforded by the decomposition of the solar rays. But it must be remembered, that the solar spectrum contains only the *primary* colours of nature, and that by mixing these colours in various proportions with each other, an indefinite variety of tints, all differing from their primaries, may be obtained.

530. "It appears that the colours of all bodies depend on some peculiar property of their surfaces, in consequence of

which, they absorb some of the coloured rays, and reflect the others. Had the surfaces of all bodies the property of reflecting the same ray only, all nature would display the monotony of a single colour, and our senses would never have known the charms of that variety which we now behold.

531. "All bodies appear of the colour of that ray, or of a tint depending on the several rays which it reflects, while all the other rays are absorbed, or, in other terms, are not reflected. *Black* and *white*, therefore, in a philosophical sense, cannot be considered as colours, since the former arises from the absorption of all the rays, and the reflection of none, and the latter is produced by the reflection of all the rays, and the absorption of none. But in all colours, or shades of colour, the rays only are reflected, of which the colour is composed. Thus, the colour of grass, and the leaves of plants, is green, because the surfaces of these substances reflect only the green rays, and absorb all the rest. For the same reason, the rose is red, the violet blue, and so of all coloured substances, every one throwing out the ray of its own colour, and absorbing all the others.

532. "To account for such a variety of colours as we see in different bodies, it is supposed that all substances, when made sufficiently thin, are transparent, and consequently, that they transmit through their surfaces, or absorb, certain rays of light, while other rays are thrown back, or reflected, as above described. Gold, for example, may be beaten so thin as to transmit some of the rays of light, and the same is true of several of the other metals, which are capable of being hammered into thin leaves. It is therefore most probable, that all the metals, could they be made sufficiently thin, would permit the rays of light to pass through them. Most, if not quite all mineral substances, though in the mass they may seem quite opaque, admit the light through their edges, when broken, and almost every kind of wood, when made no thinner than writing paper, becomes translucent. Thus we may safely conclude, that every substance with which we are acquainted, will admit the rays of light, when made sufficiently thin.

533. "Transparent colourless substances, whether solid or fluid, such as glass, water, or mica, reflect and transmit light of the same colour; that is, the light seen through these bodies, and reflected from their surfaces, is white. This is true of all transparent substances under ordinary circumstan-

ces; but if their thickness be diminished to a certain extent, these substances will both reflect and transmit coloured light of various hues, according to their thickness. Thus, the thin plates of mica, which are left on the fingers, after handling that substance, will reflect prismatic rays of various colours.

534. "There is a degree of tenuity, at which transparent substances cease to reflect any of the coloured rays, but absorb, or transmit them all, in which case they become black. This may be proved by various experiments. If a soap bubble be closely observed, it will be seen, that at first, the thickness is sufficient to reflect the prismatic rays from all its parts, but as it grows thinner, and just before it bursts, there may be seen a spot on its top, which turns black, thus transmitting all the rays at that part, and reflecting none. The same phenomenon is exhibited when a film of air or water is pressed between two plates of glass. At the point of contact, or where the two plates press each other with the greatest force, there will be a black spot, while around this there may be seen a system of coloured rings.

535. "From such experiments Sir Isaac Newton concluded that air, when below the thickness of *half a millionth of an inch*, ceases to reflect light; and also that water, when below the thickness of *three-eighths of a millionth of an inch*, ceases to reflect light; but that both air and water, when their thickness is in a certain degree above these limits, reflect all the coloured rays of the spectrum.

536. "Now all solid bodies are more or less porous, having among their particles either void spaces, or spaces filled with some foreign matter, differing in density from the body itself, such as air or water. Even gold is not perfectly compact, since water can be forced through its pores. It is most probable, then, that the parts of the same body, differing in density, either reflect or transmit the rays of light according to the size or arrangement of their particles; and in proof of this, it is found that some bodies transmit the rays of one colour, and reflect those of another. Thus the colour which passes through a leaf of gold is green, while that which it reflects is yellow.

537. "From a great variety of experiments on this subject, Sir Isaac Newton concludes that the transparent parts of bodies, according to the sizes of their transparent pores, reflect rays of one colour, and transmit those of another, for the same reason that thin plates, or minute particles of

air, water, and some other substances, reflect certain rays, and absorb or transmit others, and that this is the cause of all their colours.

538. "In confirmation of the truth of this theory, it may be observed, that many substances, otherwise opaque, become transparent by filling their pores with some transparent fluid. Thus the stone called *Hydrophane* is perfectly opaque when dry, but becomes transparent when dipped in water; and common writing paper becomes translucent after it has absorbed a quantity of oil. The transparency in these cases may be accounted for by the different refractive powers which the water and oil possess, from the stone or paper, and in consequence of which the light is enabled to pass among their particles by refraction."

QUESTIONS ON CHAP. VIII.

394. Define optics.—395. What is light? What are the two theories respecting the nature of light?—396. What are luminous bodies? What are non-luminous bodies?—397. What is a transparent body? Are glass and water perfectly transparent? How is it proved that air is perfectly transparent? What are translucent bodies? What are opaque bodies?—398. What is meant by illuminated?—399. What is a ray of light? What is a beam? What a pencil? What are divergent rays? What are convergent rays? In what direction do luminous bodies emit light? How is it proved that a luminous body fills every point within a certain distance with light?—400. Why cannot a beam of light be seen through a bent tube?—401. What is the colour of the light which different bodies throw off? If grass throws off green light, what becomes of the other rays?—402. What is the rate of velocity at which light moves? Can we perceive any difference in the time which it takes an artificial light to pass to us from a great or small distance?—403. How does the intensity of light increase and diminish? How may this ratio be illustrated?

404. What is meant by the refraction of light? Do all transparent bodies refract light equally?—405. Explain Fig. 151, and show how the ray is refracted in passing into and out of the water.—406. Explain Fig. 152, and state the reason why the shilling seems to be raised up by pouring in the water.—407.

What is a medium? In what direction must a ray of light pass towards the medium in order to be refracted?—408. Will a ray of light falling perpendicularly on a medium be refracted? Explain Fig. 153, and show how the ray E is refracted.—409. When the ray passes out of a rarer into a denser medium, in what direction is it refracted?—When it passes out of a denser into a rarer medium, in what direction is the refraction? Explain this by Fig. 154. What is the cause of refraction?—410. What is the reason that a rod, with one end in the water, appears distorted and shorter than it really is?—411. Why does the water in a pond appear less deep than it really is?

412. Suppose a sun-beam falls upon a plane mirror at right angles with its surface, in what direction will it be reflected?—413. Suppose the ray falls obliquely on its surface, in what direction will it then be reflected? What is an incident ray of light? What is a reflected ray of light?—414. What general law in optics results from observations on the incident and reflected rays?—415. Under what circumstances are the properties of reflected or transmitted light changed? What new property does it thus acquire? What is meant by polarized light? By what three ways may it be procured?—416. State one of the properties of polarized light. Explain Fig. 159. State the law deduced from this explanation.—417. What discoveries have been made by means of polarized light?

418. How many kinds of mirror are there?—419. What kind of mirror is the common looking glass? Of what use is the glass plate in the construction of this mirror?—420. Explain Fig. 160, and show how the image of an object can be seen in a plane mirror, when the real object is invisible?—422. The image of an object appears just as far behind a plane mirror, as the object is before it; explain Fig. 161, and show why this is the case.—423. What must be the comparative length of a plane mirror, in which a person may see his whole image?—424. In what part of the image, Fig. 162, are the incident and reflected rays nearly parallel? Why does the image of the lower part of the arrow appear at D?—425. Suppose the mirror, Fig. 162, to be removed, and an arrow of the same length to be placed where the image appeared, would the direction of the rays from the arrow be the same that they were from the image?

426. What is a convex mirror? What is the axis of a convex mirror?—427. What are diverging rays? What are converging rays?—429. What law governs the passage of light from and to the convex mirror?—430. Are parallel rays, falling on a convex mirror, reflected parallel? Explain Fig. 165.—432. How is

the action of the convex mirror illustrated by a number of plane mirrors?—433. Explain Fig. 167. What effect has the convex mirror upon parallel rays by reflection? What is its effect on converging rays? What is its effect on diverging rays?—434. Do the rays of light proceed only from the extremities of objects, as represented in figures, or from all their parts? Do all the rays of light proceeding from an object enter the eye, or only a few of them? What would be the consequence if the rays of light proceeded only from the parts of an object shown in diagrams?—435. Why do the images of objects reflected from convex mirrors appear curved?—436. Why do the features of the face appear out of proportion by this mirror?—437. Why does an image reflected from a convex surface appear smaller than the object?

438. Why does the half of an object appear to the eye smaller than the whole?—439. Suppose the angles C and B, Fig. 169, are equal, will there be any difference between the size of the object and its image?—440. How is the image affected, when the object is withdrawn from the surface of a convex mirror? Explain Figs. 170 and 171, and show the reason why the images are diminished when the objects are removed from the convex mirror.—441. What is said to be the first effect of withdrawing the object from a concave surface, and what the consequence on the angle of reflected rays?—442. Explain the reason why the image appears near the surface of the convex mirror.

444. What is the shape of the concave mirror, and in what respect does it differ from the convex mirror? How may convex and concave mirrors be united in the same instrument?—445. What is the difference of effect between the concave, convex, and plane mirrors, on the reflected rays?—446. In what respect may the concave mirror be considered as a number of plane mirrors?—447. What is the focus of a concave mirror? At what distance from its surface is the focus of parallel rays in this mirror?—448. What is the principal focus of a concave mirror?—449. If the incident rays are divergent, where will be the focus?—450. If the incident rays are convergent, where will be the focus?

451. When will the image from a concave mirror be larger than the object, erect, and behind the mirror? Explain Fig. 177, and show why the image is larger than the object.—452. When will the image from the concave mirror be inverted, and before the mirror?—453. What property has the concave mirror by which singular deceptions may be produced? What are these deceptions?—454. Describe the manner in which a tumbler,

with its contents, may be made to seem inverted in the air.—455. Why does the image move in a contrary direction from its object, when the object is beyond the principal focus?—456. Will the concave mirror concentrate the rays of heat, as well as those of light?—457. Suppose a luminous body to be placed in the focus of a concave mirror, in what direction will its rays be reflected?—458. Explain Fig. 180, and show why the rays from the focus of A are concentrated in the focus B.—459. What curious experiments may be made by two concave mirrors placed opposite to each other?—460. How may it be shown that heat and light are distinct principles?

461. What is a lens? What is the axis of a lens? In what part of a lens is no refraction produced? Where is the axis of a beam of light? When are rays of light said to fall directly upon a lens?—462. How many kinds of lenses are mentioned? What is the name of each? How is each of these lenses bounded?—464. On what do the focal distances of convex lenses depend? What is the focal distance of any plano-convex lens?—465. What is the focal distance of the double-convex lens? What is the shape of the double-convex lens?—466. How are divergent rays affected by passing through a convex lens? What is its effect on parallel rays?—467. What is its effect on converging rays?—468. What kind of lenses are spectacle glasses for old people? What is said to be the diameter of Mr Parker's great convex lens? What is the focal distance of this lens? What is said of its heating power?

469. What is the visual angle? Why does the same object, when seen at a distance, appear smaller than when near?—470. What is the effect of the convex lens on the visual angle? Why does an object appear larger through the convex lens than otherwise?—471. What is the effect of the concave lens? What effect does this lens have upon parallel, diverging, and converging rays? Why do objects appear smaller through this glass than they do to the naked eye?—472. Explain Figs. 188 and 189, and show the reason why the same object appears smaller in the latter.—473. What defect of the eye requires concave lenses?

474. What is the most perfect of all optical instruments? What is the form of the human eye? How many coats, or membranes, has the eye? What are they called? How many fluids has the eye, and what are they called? What is the lens of the eye called? What coat forms the white of the eye? Describe where the several coats and humours are situated. What is the iris? What is the retina? Where is the sense of vision?—

475. What is the design of Fig. 191? What is said concerning the small number of the rays which enter the eye from a visible object?—476. Why would not the rays of light give a distinct idea of the object, without refraction by the humours of the eye?

477. Explain how it is that the images of objects are inverted on the retina.—478. What experiment proves that the images of objects are inverted on the retina? Explain Fig. 193.—479. Suppose the refractive power of the eye is too great or too little, why will vision be imperfect?—480. If the cornea is too convex, where will the image be formed? How is the sight improved when the cornea is too convex? How do such lenses act to improve the sight?—481. Where do the rays tend to meet when the cornea is not sufficiently convex? How is vision assisted when the eye wants convexity? How do convex lenses help the sight of aged people?—482. Why do we see things erect, when the images are inverted on the retina?

483. What is the visual angle? How may the visual angle of the same object be increased or diminished? When do objects of different magnitudes form the same visual angle? Explain Fig. 196.—485. Under what circumstances is our sense of vision guided entirely by the visual angle? How do we judge of the magnitudes of distant objects?—486. How do we judge of the comparative size of objects near us?—487. When does a retreating object become invisible to the eye? How does a convex lens act to make us see objects which are invisible without it?—488. What is said of the actual size of an image on the retina?—489. Why are objects indistinct, when brought too near the eye?—490. Suppose objects could be seen distinctly within an inch or two of the eye, how would their dimensions be affected? How is it proved that objects placed near the eye are magnified? How does a small orifice enable us to see an object distinctly near the eye?

491. Why does a convex lens make an object distinct when near the eye? Explain Fig. 198.—492. How are the most powerful single microscopes made?—493. How many lenses form the compound microscope? Which is the object and which the eye glass? Is the object seen with this instrument, or only its image?—494. Explain Fig. 199, and show where the image is formed in this tube.—495. How many lenses has the solar microscope? Why is one of the lenses of the solar microscope called the condenser? Describe the uses of the two lenses and the reflector of the solar microscope.—496. Is the object, or only the shadow, seen by means of this instrument?

498. What is a telescope? How many kinds of telescope are

mentioned? What is the difference between them?—499. In what respect does the refracting telescope differ from the compound microscope?—500. How is the most simple refracting telescope formed? Which is the object, and which the eye lens, in Fig. 201? What is the rule by which the distance of the two glasses apart is found? How do the two glasses act, to bring an object near the eye?—501. Explain Fig. 202, and show how the object comes to be inverted by the two lenses?—502. How is the inversion of the object corrected?—503. Explain Fig. 203, and show why the two additional lenses make the image of the object erect. Does the addition of these two lenses make any difference with the apparent magnitude of the object?—504. Why cannot a highly magnifying eye glass be used in the telescope? What is the most efficacious means of increasing the power of the refracting telescope?

505. How many lenses and mirrors form the reflecting telescope? What are the advantages of the reflecting over the refracting telescope?—506. Explain Fig. 204, and show the course of the rays from the object to the eye. Why is the small mirror in this instrument made to move by means of a screw?—507. What is the advantage of the reflecting telescope in respect to the eye glass? Why is the telescope with two reflectors called Gregory's telescope?—508. How does this instrument differ from Dr Herschel's telescope? What was the focal distance and diameter of the mirror in Dr Herschel's great telescope? Where is the largest Herschel's telescope now in existence? What is the diameter and focal distance of the reflector of this telescope?

509. Describe the phenomena of the camera obscura. Why is the image formed by the camera obscura inverted? How may an outline of the image formed by the camera obscura be taken?—510. Describe the revolving camera obscura.—511. What is the magic lantern? For what purpose is this instrument employed? Describe the construction and effect of the magic lantern.

512. Is light a simple, or a compound, substance?—513. In what manner, and by what means, may light be decomposed? What are the prismatic colours, and how do they succeed each other in the spectrum? Which has the least, and which the greatest, refractive power? What is meant by homogeneous, and what by heterogeneous, colours?—514. How many primary rays of colour are there, according to Sir D. Brewster? Which are they? Explain Fig. 209, and state in what part of the spectrum these colours are respectively found. How does this

view differ from that of Newton?—515. By what other means, besides the prism, can the rays of light be decomposed? How may light be decomposed by two pieces of glass? Of what substances may prisms be formed, besides glass?—516. What is said of some liquids making the spectrum larger than others? What is said of oil of cassia, in this respect?

517. What discovery preceded the explanation of the rainbow? Who first explained the rainbow on optical principles?—518. Why does not a glass globe form a well defined spectrum? From which surface do transparent bodies chiefly reflect the light?—519. Explain Fig. 210, and show the different refractions, and the reflection concerned in forming the rainbow. In the case supposed, why will only the red ray meet the eye?—520. Suppose a person looking at a rainbow moves his eye, will he see the same colours from the same drop of rain?—521. Explain Fig. 211, and show why we see different colours from different drops of rain. Do several persons see the same rainbow at the same time? Explain the reason of this.

522. How are the colours of the primary and secondary bows arranged, in respect to each other?—523. How many refractions and reflections produce the secondary bow? Why are the colours of the secondary bow fainter than those of the primary?—524. Explain Fig. 212, and show how the secondary bow is formed.—525. In what position must the spectator be placed, in order to see the rainbow? Upon what does the size of the bow depend?—526. What is a halo? What is a parhelion?—527. How are these phenomena explained?

529. Why are the colours of objects different from those of the solar spectrum?—530. On what do the colours of bodies depend? Suppose all bodies reflected the same ray, what would be the consequence, in regard to colour?—531. Why are not black and white considered as colours? Why is the colour of grass green?—532. How is the variety of colours accounted for, by considering all bodies transparent?—533. What is said of the reflection of coloured light by transparent substances? What substance is mentioned, as illustrating this fact? When is it said that transparent substances become black?—534. How is it proved that fluids of extreme tenuity absorb all the rays and reflect none?—535. What is the conclusion of Sir Isaac Newton concerning the tenuity at which water and air cease to reflect light?—536. What is said of the porous nature of solid bodies?—537. To what conclusion did Newton arrive on this subject?—538. Illustrate this conclusion.

CHAP. IX.

OF ASTRONOMY.

539. THE term ASTRONOMY denotes the *nomos*, or *law*, which governs the *astra*,* or heavenly bodies. Its object is to investigate the magnitudes, distances, mutual relations, and motions, real or apparent, of all the visible bodies of the heavens. This wide field of inquiry has suggested a division of the subject into descriptive, physical, and practical astronomy. 1. "*Descriptive* astronomy demonstrates the magnitudes, distances, and densities of the heavenly bodies, and explains the phenomena dependant on their motions, as the change of seasons, and the vicissitudes of day and night. 2. *Physical* astronomy explains the theory of planetary motion, and the laws by which this motion is regulated and sustained. 3. *Practical* astronomy details the description and use of astronomical instruments, and develops the nature and application of astronomical calculations. The heavenly bodies are divided into three distinct classes, or systems, viz. the solar system, consisting of the sun, moon, and planets; the system of the fixed stars; and the system of the comets."

540. *Systems of astronomy.*—There are several celebrated systems, or hypotheses, for explaining the phenomena of the heavenly bodies. The principal of these are the Ptolemaic, the Copernican, and the Tychonic. 1. The *Ptolemaic* system was so named from the famous geographer Claudius Ptolemæus, who flourished in Egypt during the reigns of the Roman emperors Hadrian and Antoninus Pius. He taught *that the earth was at rest in the centre of the universe, and that the heavens revolved round it*, from east to west, in twenty-four hours, carrying all the heavenly bodies with them. This system was believed, and enjoyed an undisputed celebrity, for 1400 years. 2. The *Copernican* system derives it name from Nicholas Copernicus, who was born A. D. 1473, at Thorn in Prussia. He taught, as Pythagoras had taught before him,

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* By the term *astra*, the ancients understood not only the *stars*, properly so called, but also the sun, the moon, and all the bodies which compose the visible universe.

that the sun occupied the centre of the universe, and that the planets moved round him in elliptical orbits proportioned to their size. This system was established by the new arguments and discoveries of Galileo, Kepler, and Newton. The great principle on which it rests is gravity, or that force in nature by which all the planets are *attracted to the centre* of their respective orbits (§ 13, 80). 3. The *Tychonic* system was so named from Tycho Brahe, a noble Dane, who was born A. D. 1546, and who partly restored the system of Ptolemy concerning *the earth remaining at rest, whilst the other heavenly bodies moved round it.* He taught, however, that the moon performed a monthly revolution round the earth; that the sun was the centre of the orbits of Mercury, Venus, Mars, Jupiter, and Saturn, which revolve round him in their respective periods, as he revolves round the earth in a solar year; and, accordingly, that these five planets, together with the sun, are carried round the earth in twenty-four hours. Of these systems, the Copernican is now adopted, as furnishing the most easy and obvious explanation of the various phenomena of the heavenly bodies.

THE SOLAR SYSTEM.

541. The *solar system* comprises the sun, as a centre, and twenty-nine other bodies, which revolve round him in regular periods, and at various distances. These bodies, being perpetually in motion, are called *planets*, from the Greek word signifying wanderers, and they are distinguished, with reference to their centres of revolution, into primary and secondary. 1. *Primary* planets are those which revolve round the sun, as their proper centre. Of these there are eleven: the nearest to the sun is Mercury; then follow in succession, Venus, the Earth, Mars, Vesta, Ceres, Pallas, Juno, Jupiter, Saturn, and Herschel, or the Georgium Sidus. 2. *Secondary* planets are those which move round some primary planet, as this moves round the sun. Of these there are eighteen: the Earth is attended by one, Jupiter by four, Saturn by seven, and the Georgium Sidus by six. The secondary planets are also termed *moons*, or *satellites.*

542. *Primary planets.*—The following tabular view of the primary planets exhibits their respective diameters, their distances from the sun, the periods of their revolutions round the sun, and those of their revolutions on their own axes:—

Names of the Planets.	Diameters in English miles.	Distances from the Sun in English miles.	Periods of Revol. round the Sun.	Periods of Revolution on their own axes.		
			Days.	D.	H	M.
Mercury......	3,224	37,000,000	88	15	0	5
Venus.........	7,687	68,000,000	224¾	0	23	21
The Earth...	7,912	95,000,000	365¼	1	0	0
Mars..........	4,189	144,000,000	687	1	0	39
Vesta..........	238	225,000,000	1,335	Unknown.		
Ceres..........	163	260,000,000	1,681			
Pallas.........	80	266,000,000	1,680			
Juno...........	1,425	275,000,000	2,008	1	3	0
Jupiter.......	89,170	490,000,000	4,330½	0	9	56
Saturn........	79,042	900,000,000	10,746¾	0	10	16
Georgium Sidus...	35,112	1,800,000,000	30,637¼	0	7	0

543. The following illustration, by Sir J. Herschel, will convey a general impression of the relative magnitudes and distances of the parts of our system. "Choose any well levelled field or bowling green. On it place a globe, two feet in diameter; this will represent the Sun. Mercury will be represented by a grain of mustard seed on the circumference of a circle 164 feet in diameter for its orbit; Venus, a pea, on a circle 284 feet in diameter; the Earth also a pea, on a circle of 430 feet; Mars, a rather large pin's head, on a circle of 654 feet; Juno, Ceres, Vesta, and Pallas, grains of sand, in orbits of from 1000 to 1200 feet; Jupiter, a moderate-sized orange, on a circle nearly half-a-mile across; Saturn a small orange, on a circle of four-fifths of a mile; and Uranus (Georgium Sidus) a full-sized cherry, or small plum, upon the circumference of a circle more than a mile and a half in diameter. As to getting correct notions on this subject by drawing circles on paper, or still worse, from those very childish toys called orreries, it is out of the question. To imitate the motions of the planets, in the above-mentioned orbits, Mercury must describe its own diameter in 41 seconds; Venus, in $4^{m.}$ $14^{s.}$; the Earth, in $7^{m.}$; Mars, in $4^{m.}$ $48^{s.}$; Jupiter, in $2^{h.}$ $56^{m.}$; Saturn, in $3^{h.}$ $13^{m.}$; and Uranus, in $2^{h.}$ $16^{m.}$."—*Astronomy*, p. 287.

544. "A *year* consists of the time which it takes a planet to perform one complete revolution through its orbit, or to pass once around the sun. Our earth performs this revolution in 365 days, and therefore this is the period of our year. Mercury completes a revolution in 88 days, and therefore his

year is no longer than 88 of our days. But the planet Herschel is situated at such a distance from the sun, that his revolution is not completed in less than about 84 of our years. The other planets complete their revolutions in various periods of time between these; so that the time of these periods is generally in proportion to the distance of each planet from the sun.

545. "All the planets move round the sun *from west to east*, and in the same direction do the moons revolve round their primaries, with the exception of those of Herschel, which appear to revolve in a contrary direction. The paths in which the planets move round the sun, and in which the moons move round their primaries, are called their *orbits*. These orbits are not exactly circular, as they are commonly represented on paper, but are elliptical, or oval, so that all the planets are nearer the sun when in one part of their orbits than when in another.

546. "In addition to their annual revolutions, some of the planets are known to have *diurnal*, or daily revolutions, like our earth. The periods of these daily revolutions have been ascertained, in several of the planets, by spots on their surfaces. But where no such mark is discernible, it cannot be ascertained whether the planet has a daily revolution or not, though this has been found to be the case in every instance where spots are seen, and, therefore, there is little doubt but all have a daily, as well as a yearly motion. The *axis* of a planet is an imaginary line passing through its centre, and about which its diurnal revolution is performed. The *poles* of the planets are the extremities of this axis.

547. "The orbits of Mercury and Venus are within that of the earth, and consequently they are called *inferior* planets. The orbits of all the other planets are without, or exterior to that of the earth, and these are called *superior* planets. That the orbits of Mercury and Venus are within that of the earth, is evident from the circumstance, that they are never seen in opposition to the sun, that is, they never appear in the west, when the sun is in the east. On the contrary, the orbits of all the other planets are proved to be outside of the earth's, since these planets are sometimes seen in opposition to the sun.

548. "This will be understood by Fig. 213, where, suppose S to be the sun, M the orbit of Mercury or Venus, E the orbit of the Earth, and J that of Jupiter. Now, it is evident

that if a spectator be placed any where in the Earth's orbit, as at E, he may sometimes see Jupiter in opposition to the sun, as at J, because then the spectator would be between Jupiter and the sun. But the orbit of Venus, being surrounded by that of the Earth, she never can come in opposition to the sun, or in that part of the heavens opposite to him, as seen by us, because our Earth never passes between her and the sun.

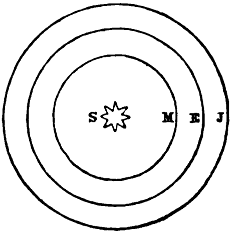

Fig. 213.

549. "It has already been stated that the orbits of the planets are elliptical, and that consequently these bodies are sometimes nearer the sun than at others. An ellipse, or oval, has two foci, and the sun, instead of being in the common centre, is always in the lower foci of their orbits. The orbit of a planet is represented by Fig. 214, where A, D, B, E, is an ellipse, with its two foci, S and O, the sun being in the focus S, which is called the lower focus. When the Earth, or any other planet, revolving around the sun, is in that part of its orbit nearest the sun, as at A, it is said to be in its *perihelion;* and when in that part which is at the greatest distance from the sun, as at B, it is said to be in its *aphelion.* The line, S D, is the mean, or average distance of a planet's orbit from the sun.

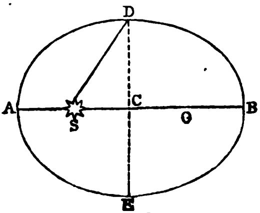

Fig. 214.

550. *Ecliptic.*—"The *planes* of the orbits of all the planets pass through the centre of the sun. The plane of an orbit is an imaginary surface, passing from one extremity, or side, of the orbit, to the other. If the rim of a drum-head be considered the orbit, its plane would be the parchment extended across it, on which the drum is beaten. Let us suppose the earth's orbit to be such a plane, cutting the sun through his centre, and extending out on every side to the starry heavens; the great circle so made, would mark the line of the *ecliptic*, or the sun's apparent path through the heavens. This circle is called the sun's *apparent* path, because the re-

volution of the earth gives the sun the appearance of passing through it. It is called the ecliptic, because eclipses happen when the moon is in, or near, this apparent path.

551. *Zodiac.*—"The zodiac is an imaginary belt, or broad circle, extending quite around the heavens. The ecliptic divides the zodiac into two equal parts, the zodiac extending 8 degrees on each side of the ecliptic, and being therefore 16 degrees wide. The zodiac is divided into 12 equal parts, called the *signs of the zodiac.*

552. "The sun appears every year to pass around the great circle of the ecliptic, and consequently, through the 12 constellations, or signs of the zodiac. But it will be seen, in another place, that the sun, in respect to the earth, stands still, and that his apparent yearly course through the heavens is caused by the annual revolution of the earth around its orbit. To understand the cause of this deception, let us suppose that S, Fig. 215, is the sun, A B, a part of the circle of the ecliptic, and C D, a part of the earth's orbit. Now, if a spectator be placed at C, he will see the sun in that part of the ecliptic marked by B, but when the earth moves in her annual revolution to D, the spectator will see the sun in that part of the heavens marked by A; so that the motion of the earth in one direction, will give the sun an apparent motion in the contrary direction.

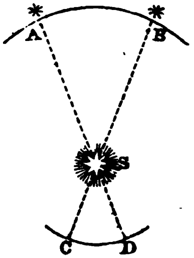

Fig. 215

553. "A sign, or *constellation*, is a collection of fixed stars, and, as we have already seen, the sun appears to move through the twelve signs of the zodiac every year. Now, the sun's place in the heavens, or zodiac, is found by his apparent conjunction, or nearness to any particular star in the constellation. Suppose a spectator at C, observes the sun to be nearly in a line with the star at B, then the sun would be near a particular star in a certain constellation. When the earth moves to D, the sun's place would assume another direction, and he would seem to have moved into another constellation, and near the star A.

554. "Each of the 12 signs of the zodiac is divided into 30 smaller parts, called *degrees;* each degree into 60 equal parts, called *minutes*, and each minute into 60 parts, called *seconds.*

555. "The division of the zodiac into *signs*, is of very ancient date, each sign having also received the name of some animal, or object, which the constellation, forming that sign, was supposed to resemble. It is hardly necessary to say, that this is chiefly the result of imagination, since the figures made by the places of the stars, never mark the outlines of the figures of animals, or other objects. This is, however, found to be the most convenient method of finding any particular star at this day, for among astronomers, any star, in each constellation, may be designated by describing the part of the animal in which it is situated. Thus, by knowing how many stars belong to the constellation Leo, or the Lion, we readily know what star is meant by that which is situated on the Lion's ear or tail."

556. The signs of the zodiac have each a special *name* and *symbol*, and are arranged in a certain order, reckoning from west to east, called the *order of the signs*. These are—♈ Aries. ♉ Taurus. ♊ Gemini. ♋ Cancer. ♌ Leo. ♍ Virgo. ♎ Libra. ♏ Scorpio. ♐ Sagittarius. ♑ Capricornus. ♒ Aquarius. ♓ Pisces. It has been decided by the Egyptian Institute that these names are derived from comparisons made by the Egyptians between celestial and terrestrial phenomena, being principally of a local nature, and belonging exclusively to a part of their own country. Thus,

1. *Capricornus.*—The first month of summer, extending from June 20 to July 20. He begins the year, and leads the celestial animals, as the goat is the leader of the flock.
2. *Aquarius.*—The second month of summer, when the inundation of the Nile is at its full extent.
3. *Pisces.* The third month of summer, when the rise of the waters cause the fish to move about.
4. *Aries.* The first month of autumn, extending from September 20 to October 20. As the waters subside, the ram returns to the pastures, leading the flocks which have been held captive by the inundation.
5. *Taurus.* The second month of autumn, denoting the period of tillage in Egypt.
6. *Gemini.* The third month of autumn, when the seeds germinate. The sign is that of two youths of different sexes.
7. *Cancer.* The first month of winter, extending from Dec. 20 to Jan. 20. The motion of the crab indicates the retrograde motion of the sun at the winter solstice.

8. *Leo*. The second month of winter. The king of animals typifies the strength and grandeur of nature at this period.
9. *Virgo*. The third month of winter. The sign denotes beauty and fruitfulness.
10. *Libra*. The first month of spring, extending from March 20 to April 20. Allusion is made to the vernal equinox, when the days and nights are equal.
11. *Scorpio*. The second month of spring, when the heat stimulates venomous reptiles, and induces disease and pestilence.
12. *Sagittarius*. The last month of spring. The centaur drives all before him; its course is drawing to a close. —*Arago*.

557. "The twelve signs of the zodiac, together with the sun, and the earth revolving around him, are represented at

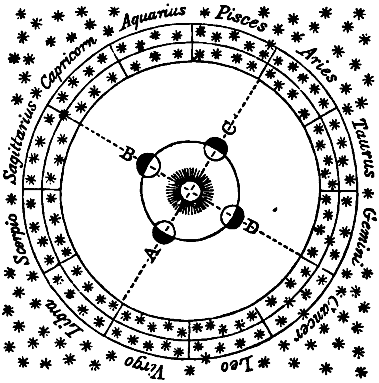

Fig. 216.

Fig. 216. When the earth is at A, the sun will appear to be just entering the sign Aries, because then, when seen from the earth, he ranges towards certain stars at the beginning of that constellation. When the earth is at C, the sun will appear in the opposite part of the heavens, and therefore in the beginning of Libra. The middle line, dividing the circle of the zodiac into equal parts, is the line of the ecliptic.

558. *Density of the planets.*—" Astronomers have no means

of ascertaining whether the planets are composed of the same kind of matter as our earth, or whether their surfaces are clothed with vegetables and forests, or not. They have, however, been able to ascertain the densities of several of them by observations on their mutual attraction. By density is meant compactness, or the quantity of matter in a given space. When two bodies are of equal bulk, that which weighs the more has the greater density. It was shown, while treating of the *properties of bodies*, that substances attract each other in proportion to the quantities of matter they contain. If, therefore, we know the dimensions of several bodies, and can ascertain the proportion in which they attract each other, their quantities of matter or densities are easily found.

559. "Thus, when the planets pass each other in their circuits through the heavens, they are often drawn a little out of the lines of their orbits by mutual attraction. As bodies attract in proportion to their quantities of matter, it is obvious that the small planets, if of the same density, will suffer greater disturbance from this cause than the large ones. But suppose two planets, of the same dimensions, pass each other, and it is found that one of them is attracted twice as far out of its orbit as the other, then, by the known laws of gravity, it would be inferred that one of them contained twice the quantity of matter that the other did, and therefore that the density of the one was twice that of the other. By calculations of this kind, it has been found that the density of the sun is but a little greater than that of water, while Mercury is more than nine times as dense as water, having a specific gravity nearly equal to that of lead. The earth has a density about five times greater than that of the sun, and a little less than half that of Mercury. The densities of the other planets seem to diminish in proportion as their distances from the sun increase, the density of Saturn, one of the most remote of the planets, being only about one-third that of water."

560. All the heavenly bodies are *spheres*, or approach nearly to the figure of a sphere. The term sphere, in geometry, denotes a solid body, described by the revolution of a semicircle about its diameter; or it may be defined to be a body bounded by a surface of which every point is equally distant from a single point within the surface, called the centre of the sphere. The spherical form of the heavenly bodies is, however, not obvious to our sight, in consequence of their

enlightened parts only being seen by us, and that at a considerable distance; hence they appear to us as plane surfaces, which are usually termed *discs*. The projection of a spherical body is always that of a circular plane. A map is nothing more than a representation, upon a plane, of some portion of the surface of a sphere. A *hemisphere* is a half-sphere, produced by cutting a sphere through the centre by a right line in any direction: thus, in reference to the earth, we speak of a northern and a southern hemisphere, an eastern and a western hemisphere, an upper and a lower hemisphere.*

THE SUN.

561. "The sun is the centre of the solar system, and the great dispenser of heat and light to all the planets. Around the sun all the planets revolve, as around a common centre, he being the largest body in our system, and, so far as we know, the largest in the universe.

562. "The distance of the sun from the earth is 95 millions of miles, and his diameter is estimated at 880,000 miles. Our globe, when compared with the magnitude of the sun, is a mere point, for his bulk is about *thirteen hundred thousand* times greater than that of the earth. Were the sun's centre placed in the centre of the moon's orbit, his circumference would reach two hundred thousand miles beyond her orbit in every direction, thus filling the whole space between us and the moon, and extending nearly as far beyond her as she is from us. A traveller, who should go at the rate of 90 miles a day, would perform a journey of nearly 33,000 miles in a year, and yet it would take such a traveller more than 80 years to go round the circumference of the sun. A body of such mighty dimensions, hanging on nothing, it is certain, must have emanated from an Almighty power.

563. "The sun appears to move around the earth every 24 hours, rising in the east, and setting in the west. This motion, as will be proved hereafter, is only apparent, and arises from the diurnal revolution of the earth on its own axis. The

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* "When the continents and seas are laid down on a globe, (and, since the discovery of Australia, we are sure that no very extensive tracts of land remain unknown, except perhaps at the south pole), we find that it is possible so to divide the globe into two hemispheres, that one shall contain *nearly all the land*, the other being almost entirely sea. It is a fact, not a little interesting to Englishmen, and, combined with our insular station in that great highway of nations, the Atlantic, not a little explanatory of our commercial eminence, that London occupies nearly the centre of the terrestrial hemisphere."—*Herschel*, p. 154.

sun, although he does not, like the planets, revolve in an orbit, is, however, not without motion, having a revolution around his own axis, once in 25 days and 10 hours. Both the fact that he has such a motion, and the time in which it is performed, have been ascertained by the spots, or *faculæ*, on his surface. If a spot is seen, on a revolving body, in a certain direction, it is obvious, that when the same spot is again seen, in the same direction, the body has made one revolution. By such spots the diurnal revolutions of the planets, as well as that of the sun, have been determined.

564. Spots on the sun seem first to have been observed in the year 1611, since which time they have constantly attracted attention, and have been the subject of investigation among astronomers. These spots change their appearance as the sun revolves on his axis, and become greater or less, to an observer on the earth, as they are turned to, or from him; they also change in respect to real magnitude and number: one spot, seen by Dr. Herschel, was estimated to be more than six times the size of our earth, being 50,000 miles in diameter. Sometimes forty or fifty spots may be seen at the same time, and sometimes only one. They are often so large as to be seen with the naked eye; this was the case in 1816.

565. "In respect to the nature and design of these spots, almost every astronomer has formed a different theory. Some have supposed them to be solid opaque masses of scoriæ, floating in the liquid fire of the sun; others, as satellites, revolving round him, and hiding his light from us; others, as immense masses, which have fallen on his disc, and which are dark coloured, because they have not yet become sufficiently heated. In two instances, these spots have been seen to burst into several parts, and the parts to fly in several directions, like a piece of ice thrown upon the ground. Others have supposed that these dark spots were the body of the sun, which became visible in consequence of openings through the fiery matter, with which he is surrounded. Dr. Herschel, from many observations with his great telescope, concludes, that the shining matter of the sun consists of a mass of phosphoric clouds, and that the spots on his surface are owing to disturbances in the equilibrium of this luminous matter, by which openings are made through it. There are, however, objections to this theory, as indeed there are to all the others,

and at present it can only be said, that no satisfactory explanation of the cause of these spots has been given.

566. "That the sun, at the same time that he is the great source of heat and light to all the solar worlds, may yet be capable of supporting animal life, has been the favourite doctrine of several able astronomers. Dr. Wilson first suggested that this might be the case, and Dr. Herschel, with his telescope, made observations which confirmed him in this opinion. The latter astronomer supposed that the functions of the sun, as the dispenser of light and heat, might be performed by a luminous, or phosphoric atmosphere, surrounding him at many hundred miles distance, while his solid nucleus might be fitted for the habitations of millions of reasonable beings. This doctrine is, however, rejected by most writers on the subject at the present day." M. Arago inclines to the opinion that the sun consists of an obscure and solid nucleus, enveloped by two atmospheres,—the one obscure, the other luminous. According to this view, the appearance of the spots is explained by ruptures occurring in the atmosphere, and exposing the globe of the sun to view. The penumbra, by which the spots are commonly surrounded, is the extremity of the inner and dark atmosphere, the rent in which is not so wide as that in the luminous one, and which is seen round the opening which exposes the central nucleus.

MERCURY.

567. "*Mercury*, the planet nearest the sun, is about 3000 miles in diameter, and revolves around him, at the distance of 37 millions of miles. The period of his annual revolution is 87 days, and he turns on his axis once in about 24 hours.

568. "No signs of an atmosphere have been observed in this planet. The sun's heat at Mercury is about seven times greater than it is on the earth, so that water, if nature follows the same laws there that she does here, cannot exist at Mercury, except in the state of steam.

569. "The nearness of this planet to the sun, and the short time his fully illuminated disc is turned towards the earth, prevent his being often seen. He may, however, sometimes be observed just before the rising, and a little after the setting of the sun. When seen after sunset, he appears a brilliant, twinkling star, showing a white light, which, however, is much obscured by the glare of twilight. When seen

in the morning, before the rising of the sun, his light is also obscured by the sun's rays.

570. "Mercury sometimes crosses the disc of the sun, or comes between the earth and that luminary, so as to appear like a small dark spot passing over the sun's face. This is called the *transit* of Mercury.

VENUS.

571. "*Venus* is the other planet, whose orbit is within that of the earth. Her diameter is about 8600 miles, being somewhat larger than the earth. Her revolution around the sun is performed in 224 days, at the distance of 68 millions of miles from him. She turns on her axis once in 23 hours, so that her day is a little shorter than ours.

572. "Venus, as seen from the earth, is the most brilliant of all the primary planets, and is better known than any nocturnal luminary except the moon. When seen through a telescope, she exhibits the phases or horned appearance of the moon, and her face is sometimes variegated with dark spots. Venus may often be seen in the day time, even when she is in the vicinity of the blazing light of the sun. A luminous appearance around this planet, seen at certain times, proves that she has an atmosphere. Some of her mountains are several times more elevated than any on our globe, being from 10 to 22 miles high. Venus sometimes makes a transit across the sun's disc, in the same manner as Mercury, already described. The transits of Venus occur only at distant periods from each other. The last transit was in 1769, and the next will not happen until 1874. These transits have been observed by astronomers with the greatest care and accuracy, since it is by observations on them that the true distances of the earth and planets from the sun are determined.

573. "When Venus is in that part of her orbit which gives her the appearance of being west of the sun, she rises before him, and is then called the *morning* star; and when she appears east of the sun, she is behind him in her course, and is then called the *evening* star. These periods do not agree, either with the yearly revolution of the earth, or of Venus, for she is alternately 290 days the morning star, and 290 days the evening star. The reason of this is, that the earth and Venus move round the sun in the same direction, and hence her relative motion, in respect to the earth, is

much slower than her absolute motion in her orbit. If the earth had no yearly motion, Venus would be the morning star one-half of the year, and the evening star the other half.

THE EARTH.

574. "The next planet in our system, nearest the sun, is the earth. Her diameter is 7912 miles. This planet revolves around him in 365 days, 5 hours, and 48 minutes; and at the distance of 95 millions of miles. She turns round her own axis once in 24 hours, making a day and a night. The earth's revolution around the sun is called her *annual*, or *yearly* motion, because it is performed in a year; while the revolution around her own axis, is called the *diurnal* or daily motion, because it takes place every day. The figure of the earth, with the phenomena connected with her motion will be explained in another place.

THE MOON.

575. "The moon, next to the sun, is, to us, the most brilliant and interesting of all the celestial bodies. Being the nearest to us of any of the heavenly orbs, and apparently designed for our use, she has been observed with great attention, and many of the phenomena which she presents, are therefore better understood and explained, than those of the other planets.

576. "While the earth revolves round the sun in a year, it is attended by the moon, which makes a revolution round the earth once in 27 days, 7 hours, and 43 minutes. The distance of the moon from the earth is 240,000 miles, and her diameter about 2000 miles. Her surface, when seen through a telescope, appears diversified with hills, mountains, valleys, rocks, and plains, presenting a most interesting and curious aspect; but the explanation of these phenomena are reserved for another section.

MARS.

577. "The next planet in the solar system, is Mars, his orbit surrounding that of the earth. The diameter of this planet is upwards of 4000 miles, being about half that of the earth. The revolution of Mars around the sun is performed in nearly 687 days, or in somewhat less than two of our years, and he turns on his axis once in 24 hours and 40 minutes. His mean distance from the sun is 144 millions

of miles, so that he moves in his orbit at the rate of about 55,000 miles in an hour. The days and nights, at this planet, and the different seasons of the year, bear a considerable resemblance to those of the earth. The density of Mars is less than that of the earth, being only three times that of water.

578. "Mars reflects a dull red light, by which he may be distinguished from the other planets. His appearance through the telescope is remarkable for the great number and variety of spots which his surface presents. Mars has an atmosphere of great density and extent, as is proved by the dim appearance of the fixed stars when seen through him. When any of the stars are seen nearly in a line with this planet, they give a faint, obscure light, and the nearer they approach the line of his disc, the fainter is their light, until the star is entirely obscured from the sight. The sun's heat at this planet is less than half that which we enjoy.

579. "This planet sometimes appears much larger to us than at others, and this is readily accounted for by his greater or less distance. At his nearest approach to the earth, his distance is only fifty millions of miles, while his greatest distance is 240 millions of miles; making a difference in his distance of 190 millions of miles, or the diameter of the earth's orbit.

580. "To the inhabitants of Mars, our planet appears alternately as the morning and evening star, as Venus does to us, and as Mercury does to Venus.

VESTA, JUNO, PALLAS, AND CERES.

581. "These planets were unknown until recently, and are therefore sometimes called the *new* planets. They are the smallest of all the planets, and have therefore been called *Asteroids*.

582. "The orbit of *Vesta* is next in the solar system to that of Mars. This planet was discovered by Dr Olbers, of Bremen, in 1807. The light of Vesta is of a pure white, and in a clear night she may be seen with the naked eye, appearing about the size of a star of the 5th or 6th magnitude. Her revolution round the sun is performed in 3 years and 66 days, at the distance of 223 millions of miles from him.

583. "*Juno* was discovered by Mr Harding of Bremen, in 1804. Her mean distance from the sun is 253 millions of miles. Her orbit is more elliptical than that of any other

planet, and, in consequence, she is sometimes 127 millions of miles nearer the sun than at others. This planet completes its annual revolution in 4 years and about 4 months, and revolves round its axis in 27 hours. Its diameter is 1400 miles.

584. "*Pallas* was also discovered by Dr Olbers, in 1802. Her distance from the sun is 226 millions of miles, and her periodic revolution round him, is performed in 4 years and 7 months.

585. "*Ceres* was discovered in 1801, by Piazzi, of Palermo. This planet performs her revolution in the same time as Pallas, being 4 years and 7 months. Her distance from the sun is 260 millions of miles. According to Dr Herschel, this planet is only about 160 miles in diameter.

JUPITER.

586. "Jupiter is 89,000 miles in diameter, and performs his annual revolution once in about 11 years, at the distance of 490 millions of miles from the sun. This is the largest planet in the solar system, being about 1400 times larger than the earth. His diurnal revolution is performed in nine hours and fifty-five minutes, giving his surface, at the equator, a motion of 28,000 miles per hour. This motion is about twenty times more rapid than that of our earth at the equator

587. "Jupiter, next to Venus, is the most brilliant of the planets, though the light and heat of the sun on him are nearly 25 times less than on the earth.

588. "This planet is distinguished from all the others, by an appearance resembling bands, which extend across his disc. These are termed *belts*, and are variable, both in respect to number and appearance. Sometimes seven or eight are seen,

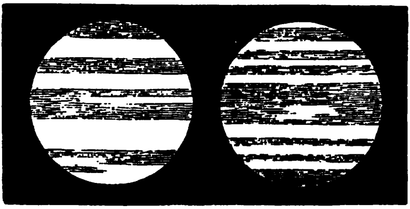

Fig. 217.

several of which extend quite across his face, while others appear broken, or interrupted. These bands, or belts, when the planet is observed through a telescope, appear as represented in Fig. 217. This appearance is much the most common, the belts running quite across the face of the planet in parallel lines. Sometimes, however, his aspect is quite different from this, for in 1780, Dr Herschel saw the whole disc of Jupiter covered with small curved lines, each of which appeared broken, or interrupted, the whole having a parallel direction across his disc, as in Fig. 218.

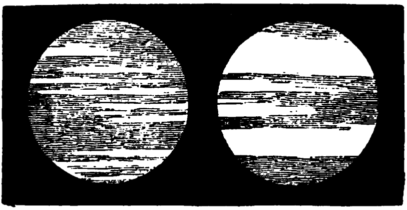

Fig. 218.

589. "Different opinions have been advanced by astronomers respecting the cause of these appearances. By some they have been regarded as clouds, or as openings in the atmosphere of the planet, while others imagine that they are the marks of great natural changes, or revolutions, which are perpetually agitating the surface of that planet. It is, however, most probable, that these appearances are produced by the agency of some cause, of which we, on this little earth, must always be entirely ignorant.

590. "Jupiter has four satellites, or moons, two of which are sometimes seen with the naked eye. They move round, and attend him in his yearly revolution, as the moon does our earth. They complete their revolutions at different periods, the shortest of which is less than two days, and the longest seventeen days.

591. "These satellites often fall into the shadow of their primary, in consequence of which they are eclipsed, as seen from the earth. The eclipses of Jupiter's moons have been observed with great care by astronomers, because they have been the means of determining the exact longitude of places, and the velocity with which light moves through space. How longitude is determined by these eclipses, cannot be

explained or understood at this place, but the method by which they become the means of ascertaining the velocity of light, may be readily comprehended. An eclipse of one of these satellites appears, by calculation, to take place sixteen minutes sooner, when the earth is in that part of her orbit nearest to Jupiter, than it does when the earth is in that part of her orbit at the greatest distance from him. Hence, light is found to be sixteen minutes in crossing the earth's orbit, and as the sun is in the centre of this orbit, or nearly so, it must take about 8 minutes for the light to come from him to us. Light, therefore, passes at the velocity of 95 millions of miles, our distance from the sun, in about 8 minutes, which is nearly 200 thousand miles in a second.

SATURN.

592. "The planet Saturn revolves round the sun in a period of about 30 of our years, and at the distance from him of 900 millions of miles. His diameter is 79,000 miles making his bulk nearly nine hundred times greater than that of the earth, but notwithstanding this vast size, he revolves on his axis once in about ten hours. Saturn, therefore, performs upwards of 25,000 diurnal revolutions in one of his years, and hence his year consists of more than 25,000 days; a period of time equal to more than 10,000 of our days. On account of the remote distance of Saturn from the sun, he receives only about a 90th part of the heat and light which we enjoy on the earth. But to compensate, in some degree, for this vast distance from the sun, Saturn has seven moons, which revolve round him at different distances, and at various periods, from 1 to 80 days.

593. "Saturn is distinguished from the other planets by his *ring*, as Jupiter is by his belt. When this planet is viewed through a telescope, he appears surrounded by an

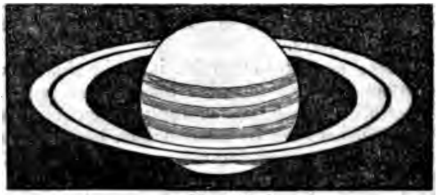

Fig. 219.

immense luminous circle, which is represented by Fig. 219. There are indeed two luminous circles, or rings, one within the other, with a dark space between them, so that they do not appear to touch each other. Neither does the inner ring touch the body of the planet, there being, by estimation, about the distance of thirty thousand miles between them. The external circumference of the outer ring is 640,000 miles, and its breadth from the outer to the inner circumference, 7,200 miles, or nearly the diameter of our earth. The dark space between the two rings, or the interval between the inner and the outer ring, is 2,800 miles. This immense appendage revolves round the sun with the planet,—performs daily revolutions with it, and, according to Dr Herschel, is a solid substance, equal in density to the body of the planet itself.

594. "The design of Saturn's ring, an appendage so vast, and so different from any thing presented by the other planets, has always been a matter of speculation and inquiry among astronomers. One of its most obvious uses appears to be that of reflecting the light of the sun on the body of the planet, and possibly it may reflect the heat also, so as in some degree to soften the rigour of so inhospitable a climate.

595. "As this planet revolves around the sun, one of its sides is illuminated during one half of the year, and the other side during the other half; so that, as Saturn's year is equal to thirty of our years, one of his sides will be enlightened and darkened, alternately, every fifteen years, as the poles of our earth are alternately in the light and dark every year.

596. "Fig. 220 represents Saturn as seen by an eye placed at right angles to the plane of his ring. When seen from the earth, his position is always oblique, as represented by this figure. The inner white circle, represents the body of the planet, enlightened by the sun. The dark circle, next to this, is the unenlightened space between the body of the planet and the inner ring, being the dark expanse of the heavens beyond the planet. The two white circles are the rings of the planet, with the dark space between them, which also is the dark expanse of the heavens.

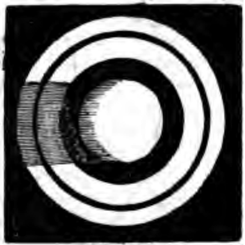
Fig. 220.

HERSCHEL.

597. "In consequence of some inequalities in the motions of Jupiter and Saturn, in their orbits, several astronomers had suspected that there existed another planet beyond the orbit of Saturn, by whose attractive influence these irregularities were produced. The conjecture was confirmed by Dr Herschel, in 1781, who in that year discovered the planet, which is now generally known by the name of its discoverer, though called by him *Georgium sidus*. The orbit of Herschel is beyond that of Saturn, and at the distance of 1800 millions of miles from the sun. To the naked eye this planet appears like a star of the sixth magnitude, being, with the exception of some of the comets, the most remote body, so far as is known, in the solar system.

598. "Herschel completes his revolution round the sun in nearly 84 of our years, moving in his orbit at the rate of 15,000 miles in an hour. His diameter is 35,000 miles, so that his bulk is about eighty times that of the earth. The light and heat of the sun at Herschel is about 360 times less than it is at the earth, and yet it has been found, by calculation, that this light is equal to 248 of our full moons, a striking proof of the inconceivable quantity of light emitted by the sun.

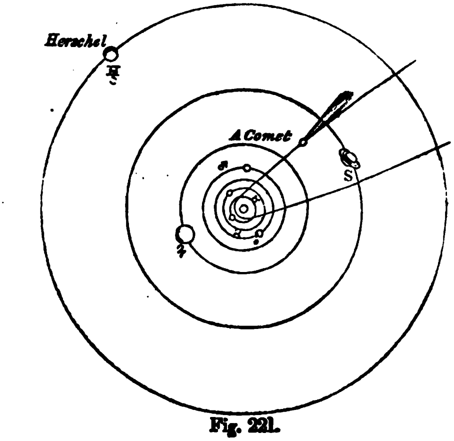

Fig. 221.

599. “This planet has six satellites, which revolve round him at various distances, and in different times. The periods of some of these have been ascertained, while those of the others remain unknown.

600. “*Relative situations of the planets.*—Having now given a short account of each planet composing the solar system, the relative situations of their several orbits, with the exception of those of the Asteroids, are shown by Fig. 221, in which the orbits are marked by the signs of each planet, of which the first, or that nearest the sun, is Mercury, the next Venus, the third the Earth, the fourth Mars; then come those of the Asteroids, then Jupiter, then Saturn, and lastly Herschel.

601. “*Comparative dimensions of the planets.*—The comparative dimensions of the planets are delineated at Fig. 222.

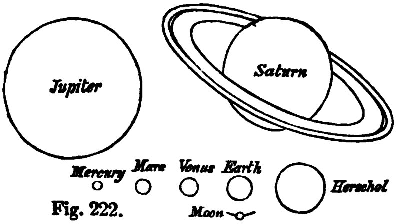

Fig. 222.

PARALLAX.

602. When the position of a heavenly body is observed from different parts of the earth's surface, it is by no means referred to the same point in the heavens: the *apparent* position of the luminary changes with the actual position of the observer. This difficulty does not occur in the case of the fixed stars, which are placed at such infinite distances from our globe, that the visual rays, proceeding from any individual star to different parts of the earth, may be considered parallel. This supposition cannot, however, be made with respect to those bodies which compose the solar system, since they are very much nearer to us, and are consequently seen in different directions from different points of observation. It is, accordingly, necessary to consider more particularly the effect of this difference of situation, and to find the means of applying the proper correction.

603. The term *parallax* denotes simply a change of place or of aspect. In astronomical language, however, it is restricted

to the difference of apparent positions of any celestial object when viewed from a station on the *surface* of the earth, and from its *centre*. The *centre of the earth* is the general station to which all astronomical observations are referred; but as we observe from the surface, a *reduction to the centre* is needed; and the amount of this reduction is called parallax. In other words, the parallax of a body signifies the difference between its *apparent* place and its *true* place, or that in which it would be seen, if the observer were situated at the centre to which the motion is referred. When the point of reference is the centre of the earth itself, the change of aspect is called the *diurnal parallax*; when it is the centre of the earth's orbit, the change is called the *annual* parallax.

604. "*Diurnal parallax.*—The diurnal parallax of a heavenly body will be readily understood by reference to the diagram, Fig. 223. Let C be the centre of the earth, A the place of the observer, Z his zenith, and S a heavenly body. On observing the body from A, it will be seen in the direction A S, making the angle Z A S with the zenith. But if the observer could be placed at C, he would see the body in the direction C S, making the angle Z C S with the zenith. The difference between these two angles Z A S and Z C S is the parallax of S, which, therefore, is equal to the angle A S C. Hence it appears that the parallax of a celestial body is the angle comprised between two lines drawn from the body, the one to the centre of the earth, and the other to a point on its surface. On account of the immense distance of the fixed stars, the diurnal parallax is altogether insensible with regard to them. It may amount to a degree in respect of the moon; but the greatest parallax of the nearest planet does not exceed 30″. It is evident from the inspection of the figure, that, although the distance of the object S remains the same, the angle A S C is not a constant quantity, but is greatest when S is seen in the direction of the horizon A H, and diminishes as the altitude of S increases, until it vanishes altogether at the zenith, where the two lines A S and C S merge into the line C Z.

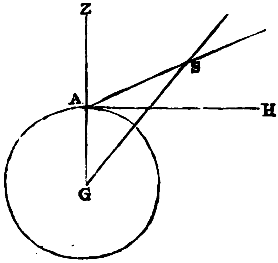

Fig. 223.

605. "*Annual parallax.*—In what has yet been said, the centre of the earth has been taken as the point of reference, and therefore regard has only been had to the difference of apparent situation occasioned by the eccentric position of the observer at the surface of the earth. But the sun, and not the earth, may be regarded as the centre to which the motion is referred, and the position of any celestial body of which the distance from the sun is not so great as to be incomparable with the semidiameter of the earth's orbit, would be different if viewed from the sun, from what it is when viewed from the earth. This difference is called the *annual parallax*, or *parallax of the great orb.* It is the angle under which the semidiameter of the earth's orbit would be seen from a superior planet, or from a fixed star. Such, however, is the enormous distance even of the nearest fixed stars, that, excepting two or three instances, which perhaps may still be regarded as doubtful, not one of them has yet been discovered to be sensibly affected by annual parallax; though observations have been carried to such nicety, that, did the quantity in question amount to a single second, it could not possibly have escaped detection."—*Brande's Dict. of Science, &c.*

MOTIONS OF THE PLANETS.

606. "We have seen, in a former part of this work, that all undisturbed motion is straight forward, and that a body projected into open space, would continue perpetually to move in a right line, unless retarded or drawn out of this course by some external cause. To account for the motions of the planets in their orbits, we will suppose that the earth, at the time of its creation, was thrown by the hand of the Creator into open space, the sun having been before created, and fixed in his present place.

607. "Under *compound motion*, it has been shown, that when a body is acted on by two forces perpendicular to each other, its motion will be in a diagonal line between the direction of the two forces. But we will again here suppose that a ball be moving in the line M X, Fig. 224, with a given force, and that another force half as great should strike it in the direction of N, the ball would then describe the diagonal of a parallelogram, whose length would be just

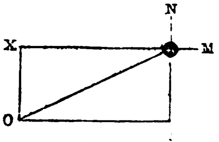

Fig. 224.

equal to twice its breadth, and the line of the ball would be straight, because it would obey the impulse and direction of these two forces only.

608. "Now let A, Fig. 225, represent the earth, and S the sun; and suppose the earth to be moving forward, in the line from A to B, and to have arrived at A, with a velocity sufficient, in a given time, and without disturbance, to carry it to B. But at the point A, the sun, S, acts upon the earth with his attractive power, and with a force which would draw it to C, in the same space of time that it would otherwise have gone to B. Then the earth, instead of passing to B, in a straight line, would be drawn down to D, the diagonal of the parallelogram A, B, D, C. The line of direction, in Fig. 224, is straight, because the body moved obeys only the direction of the two forces; but it is curved from A to D, Fig. 225, in consequence of the continued force of the sun's attraction, which produces a constant deviation from a right line. When the earth arrives at D, still retaining its projectile or centrifugal force, its line of direction would be towards N, but while it would pass along to N without disturbance, the attracting force of the sun is again sufficient to bring it to E, in a straight line, so that, in obedience to the two impulses, it again describes the curve to O.

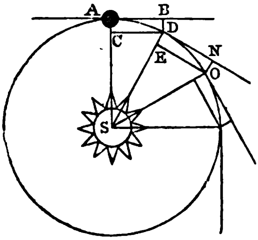

Fig. 225.

609. "It must be remembered, in order to account for the circular motions of the planets, that the attractive force of the sun is not exerted at once, or by a single impulse, as is the case with the cross forces, producing a straight line, but that this force is imparted by degrees, and is constant. It therefore acts equally on the earth, in all parts of the course from A to D, and from D to O. From O, the earth, having the same impulses as before, moves in the same curved or circular direction, and thus its motion is continued perpetually.

610. "The tendency of the earth to move forward in a straight line, is called the *centrifugal force*, and the attraction of the sun, by which it is drawn downwards, or towards

a centre, is called its *centripetal force*, and it is by these two forces that the planets are made to perform their constant revolutions around the sun.

611. "In the above explanation, it has been supposed that the sun's attraction, which constitutes the earth's gravity, was at all times equal, or that the earth was at an equal distance from the sun, in all parts of its orbit. But, as heretofore explained, the orbits of all the planets are *elliptical*, the sun being placed in the lower focus of the ellipse. The sun's attraction is, therefore, stronger in some parts of their orbits than in others, and for this reason their velocities are greater at some periods of their revolutions than at others.

612. "To render this intelligible, suppose, as before, that the centrifugal and centripetal forces so balance each other, that the earth moves round the circular orbit A E B, Fig. 226, until it comes to the point E; and at this point, let us suppose that the gravitating force is too strong for the force of projection, so that the earth, instead of continuing its former direction towards B, is attracted by the sun S, in the curve E C. When at C, the line of the earth's projectile force, instead of tending to carry it farther from the sun, as would be the case, were it revolving in a circular orbit, now tends to draw it still nearer to him, so that at this point, it is impelled by both forces towards the sun. From C, therefore, the force of gravity increasing in proportion as the square of the distance between the sun and earth diminishes, the velocity of the earth will be uniformly accelerated, until it arrives at the point nearest the sun, D. At this part of its orbit, the earth will have gained, by its increased velocity, so much centrifugal force, as to give it a tendency to overcome the sun's attraction, and to fly off in the line D O. But the sun's attraction being also increased by the near approach of the earth, the earth is retained in its orbit, notwithstanding its increased centrifugal force, and it therefore passes through the opposite part of its orbit, from D to G, at the same distance from him that it approached. As the earth passes from the sun, the force of gravity tends continually

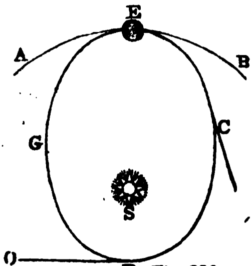

Fig. 226.

to retard its motion, as it did to increase it while approaching him. But the velocity it had acquired in approaching the sun, gives it the same rate of motion from D to G, that it had from C to D. From G, the earth's motion is uniformly retarded, until it again arrives at E, the point from which it commenced, and from whence it describes the same orbit, by virtue of the same forces, as before. The earth, therefore, in its journey round the sun, moves at very unequal velocities, sometimes being retarded, and then again accelerated, by the sun's attraction.

613. "It is an interesting circumstance, respecting the motions of the planets, that if the contents of their orbits be divided into unequal triangles, the acute angles of which centre at the sun, with the line of the orbit for their bases, the centre of the planet will pass through each of these bases in equal times. This will be understood by Fig. 227, the elliptical circle being supposed to be the earth's orbit, with the sun, S, in one of the foci. Now the spaces 1, 2, 3, &c. though of different shapes, are of the same dimensions, or contain the same quantity of surface. The earth, we have already seen, in its journey round the sun, describes an ellipse, and moves more rapidly in one part of its orbit than in another. But whatever may be its actual velocity, its comparative motion is through equal areas in equal times. Thus its centre passes from E to C, and from C to B, in the same period of time, and so of all the other divisions marked in the figure. If the figure, therefore, be considered the plane of the earth's orbit, divided into 12 equal areas, answering to the 12 months of the year, the earth will pass through the same areas in every month, but the spaces through which it passes will be increased, during every month, for one half the year, and diminished, during every month, for the other half.

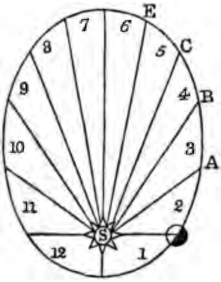

Fig. 227.

614. "The reason why the planets, when they approach near the sun, do not fall to him, in consequence of his increased attraction, and why they do not fly off into open space, when they recede to the greatest distance from him, may be thus explained:—

615. "Taking the earth as an example, we have shown that when in the part of her orbit nearest the sun, her velocity is greatly increased by his attraction, and that consequently the earth's centrifugal force is increased in proportion. As an illustration of this, we know that a thread which will sustain an ounce ball, when whirled round in the air, at the rate of 50 revolutions in a minute, would be broken were these revolutions increased to the number of 60 or 70 in a minute, and that the ball would then fly off in a straight line. This shows that when the motion of a revolving body is increased, its centrifugal force is also increased. Now, the velocity of the earth increases in an inverse proportion, as its distance from the sun diminishes, and in proportion to the increase of velocity is its centrifugal force increased; so that, in any other part of its orbit, except when nearest the sun, this increase of velocity would carry the earth away from its centre of attraction. But this increase of the earth's velocity is caused by its near approach to the sun, and consequently the sun's attraction is increased, as well as the earth's velocity. In other terms, when the centrifugal force is increased, the centripetal force is increased in proportion, and thus, while the centrifugal force prevents the earth from falling to the sun, the centripetal force prevents it from moving off in a straight line.

616. "When the earth is in that part of its orbit most distant from the sun, its projectile velocity being retarded by the counter force of the sun's attraction, becomes greatly diminished, and then the centripetal force becomes stronger than the centrifugal, and the earth is again brought back by the sun's attraction, as before, and in this manner its motion goes on without ceasing. It is supposed, as the planets move through spaces void of resistance, that their centrifugal forces remain the same as when they first emanated from the hand of the Creator, and that this force, without the influence of the sun's attraction, would carry them forward into infinite space."

KEPLER'S LAWS.

617. The laws of elliptic motion about the sun as a focus, and of the equable description of areas by lines joining the sun and planets, were originally established by Kepler, from a consideration of the observed motion of Mars; and were by him extended, analogically, to all the other planets. These laws are three:—

1. *That every planet moves so that the line drawn from it to the sun describes about the sun areas proportional to the times.*
2. *That the planets all move in elliptic orbits, of which the sun occupies one of the foci.*
3. *That the squares of the times of the revolutions of the planets are as the cubes of their mean distances from the sun.*

The announcement of these laws by Kepler led to a further inquiry into the causes which governed these movements. 1. From the first law, Newton concluded *that the force acting on the planets is directed towards the centre of the sun.* 2. From the second law, he determined *that the force acting on the planets is in the inverse ratio of the square of the distance of their centres from that of the sun.* 3. From the third law, he found *that the force is proportionate to the mass.*

618. *Kepler's first law.*—"The first law of Kepler gives us no information as to the nature or intensity of the force urging the planets to the sun; the only conclusion it involves, is that it does so urge them. It is a property of orbitual rotation under the influence of central forces *generally*, and, as such, we daily see it exemplified in a thousand familiar instances. A simple experimental illustration of it, is to tie a bullet to a thin string, and, having whirled it round with a moderate velocity in a vertical plane, to draw the end of the string through a small ring, or allow it to coil itself round the finger or a cylindrical rod held very firmly in a horizontal position. The bullet will then approach the centre of motion in a spiral line; and the increase not only of its angular but of its linear velocity, and the rapid diminution of its periodic time when near the centre, will express, more clearly than any words, the compensation by which its uniform description of areas is maintained under a constantly diminishing distance. If the motion be reversed, and the thread allowed to uncoil, beginning with a rapid impulse, the velocity will diminish by the same degrees as it before increased. The increasing rapidity of a dancer's *pirouette*, as he draws in his limbs and straightens his whole person, so as to bring every part of his frame as near as possible to the axis of his motion, is another instance where the connection of the observed effect with the central force exerted, though equally real, is much less obvious."—*Herschel's Astronomy.*

619. *Kepler's second law.*—"The second law of Kepler

involves, as a consequence, the *law* of solar gravitation (so be it allowed to call the force, whatever it be, which urges them towards the sun), as exerted on each individual planet, apart from all connection with the rest. A straight line, dynamically speaking, is the only path which can be pursued by a body *absolutely free*, and under the action of *no* external force. All *deflection* into a curve is evidence of the exertion of a force; and the greater the deflection in equal times, the more intense the force. Deflection from a straight line is only another word for *curvature* of path; and, as a circle is characterized by the uniformity of its curvature in all its parts, so is every other curve (as an ellipse) characterized by the particular *law* which regulates the increase and diminution of its curvature as we advance along its circumference. The deflecting force, then, which continually bends a moving body in a curve, may be ascertained, provided its direction, in the first place, and secondly, the law of curvature of the curve itself, be known. Both these enter as elements into the expression of the force. A body may describe, for instance, an ellipse, under a great variety of dispositions of the acting forces: it may glide along, for example, as a bead upon a polished wire, bent into an elliptic form; in which case the acting force is always perpendicular to the wire, and the velocity is uniform. In this case the *force* is directed to *no fixed* centre, and there is no equable description of areas at all. Or it may describe it as we may see done, if we suspend a ball by a *very* long string, and, drawing it a little aside from the perpendicular, throw it *round* with a gentle impulse. In this case the acting force is directed to the centre of the ellipse, about which areas are described equably, and *to* which a force *proportional* to the distance (the decomposed result of terrestrial gravity) perpetually urges it. This is at once a very easy experiment, and a very instructive one.

620. "In the case before us, of an ellipse described by the action of a force directed to the *focus*, the steps of the investigation of the law of force are these: 1st, The law of the areas determines the actual *velocity* of the revolving body at every point, or the space really run over by it in a given minute portion of time; 2dly, The law of curvature of the ellipse determines the linear amount of deflection from the tangent *in the direction of the focus*, which corresponds to that space so run over; 3dly, and lastly, The laws of accelerated motion declare that the intensity of the acting force

causing such deflection *in its own direction*, is measured by, or proportional to, the amount of that deflection, and may therefore be calculated in any particular position, or generally expressed by geometrical or algebraical symbols, *as a law* independent of particular positions, when that deflection is so calculated or expressed. We have here the spirit of the process by which Newton has resolved this interesting problem. For its geometrical detail, we must refer to the third section of his *Principia*. We know of no artificial mode of imitating this species of elliptic motion; though a rude approximation to it—enough, however, to give a conception of the alternate approach and recess of the revolving body to and from the focus, and the variation of its velocity—may be had by suspending a small steel bead to a fine and very long silk fibre, and setting it to revolve in a small orbit round the pole of a powerful cylindrical magnet, held upright, and vertically under the point of suspension."—*Ibid.*

621. *Kepler's third law.*—"The third law of Kepler, which connects the distances and periods of the planets by a general rule, bears with it, as its theoretical interpretation, this important consequence, viz., that it is one and the same force, modified only by distance from the sun; which retains *all* the planets in their orbits about it. That the attraction of the sun (if such it be) is exerted upon all the bodies of our system indifferently, without regard to the peculiar materials of which they may consist, in the exact proportion of their inertiæ, or quantities of matter; that it is not, therefore, of the nature of the elective attractions of chemistry, or of magnetic action, which is powerless on other substances than iron and some one or two more, but is of a more universal character, and extends equally to all the material constituents of our system, and to those of other systems than our own.

622. "This law, important and general as it is, results, as the simplest of corollaries, from the relations established by Newton in the section of the *Principia* referred to (prop. 15), from which proposition it results, that if the earth were taken from its actual orbit, and launched anew in space at the place, in the direction, and with the velocity of any of the other planets, it would describe the very same orbit, and in the same period, which that planet actually does, a very minute correction of the period only excepted, arising from the difference between the mass of the earth and that of the planet. Small as the planets are compared with the sun, some of

them are not, as the earth is, mere atoms in the comparison. The strict wording of Kepler's law, as Newton has proved in his fifty-ninth proposition, is applicable only to the case of planets whose proportion to the central body is absolutely inappreciable. When this is not the case, the periodic time is shortened in the proportion of the square root of the number expressing the sun's mass or inertia, to that of the sum of the numbers expressing the masses of the sun and planet; and in general, whatever be the masses of two bodies revolving round each other under the influence of the Newtonian law of gravity, the square of their periodic time will be expressed by a fraction, whose numerator is the cube of their mean distance, *i. e.* the greater semi-axis of their elliptic orbit, and whose denominator is the sum of their masses. When one of the masses is incomparably greater than the other, this resolves itself into Kepler's law; but when this is not the case, the proposition thus generalized stands in lieu of that law. In the system of the sun and planets, however, the numerical correction, thus introduced into the results of Kepler's law, is too small to be of any importance, the mass of the largest of the planets (Jupiter) being much less than a thousandth part of that of the sun."—*Ibid.*

THE EARTH.

623. "It is almost universally believed in the present day, that the *apparent* daily motion of the heavenly bodies *from east to west*, is caused by the *real* motion of the earth *from west to east*, and yet there are comparatively few who have examined the evidence on which this belief is founded. For this reason, we will here state the most obvious, and to a common observer, the most convincing proofs of the earth's revolution. These are, first, the inconceivable velocity of the heavenly bodies, and particularly of the fixed stars around the earth, if she stands still. Second, the fact, that all astronomers of the present age agree that every phenomenon which the heavens present, can be best accounted for, by supposing the earth to revolve. Third, the analogy to be drawn from many of the other planets, which are known to revolve on their axis; and fourth, the different lengths of days and nights at the different planets, for did the sun revolve about the solar system, the days and nights at many of the planets must be of similar lengths.

624. "The distance of the sun from the earth being 95

millions of miles, the diameter of the earth's orbit is twice its distance from the sun, and therefore 190 millions of miles. Now, the diameter of the earth's orbit, when seen from the nearest fixed star, is a mere point, and were the orbit a solid mass of opaque matter, it could not be seen, with such eyes as ours, from such a distance. This is known by the fact, that these stars appear no larger to us, even when our sight is assisted by the best telescopes, when the earth is in that part of her orbit nearest them, than when at the greatest distance, or in the opposite part of her orbit. The approach, therefore, of 190 millions of miles towards the fixed stars, is so small a part of their whole distance from us, that it makes no perceptible difference in their appearance. Now, if the earth does not turn on her axis once in 24 hours, these fixed stars must revolve around the earth at this amazing distance once in 24 hours. If the sun passes around the earth in 24 hours, he must travel at the rate of nearly 400,000 miles in a minute; but the fixed stars are at least 400,000 times as far beyond the sun, as the sun is from us, and, therefore, if they revolve around the earth, must go at the rate of 400,000 times 400,000 miles, that is, at the rate of 160,000,000,000, or 160 billions of miles in a minute; a velocity of which we can have no more conception than that of infinity or eternity.

625. "In respect to the analogy to be drawn from the known revolutions of the other planets, and the different lengths of days and nights among them, it is sufficient to state, that to the inhabitants of Jupiter, the heavens appear to make a revolution in about 10 hours, while to those of Venus, they appear to revolve once in 23 hours, and to the inhabitants of the other planets a similar difference seems to take place, depending on the periods of their diurnal revolutions. Now, there is no more reason to suppose that the heavens revolve round us, than there is to suppose that they revolve around any of the other planets, since the same apparent revolution is common to them all; and as we know that the other planets, at least many of them, turn on their axis, and as all the phenomena presented by the earth, can be accounted for by such a revolution, it is folly to conclude otherwise.

CIRCLES AND DIVISIONS OF THE EARTH.

626. "It will be necessary for the pupil to retain in his memory the names and directions of the following lines, or

circles, by which the earth is divided into parts. These lines, it must be understood, are entirely imaginary, there being no such divisions marked by nature on the earth's surface. They are, however, so necessary, that no accurate description of the earth, or of its position with respect to the heavenly bodies, can be conveyed without them.

627. "The earth, whose diameter is 7912 miles, is represented by the globe, or sphere, Fig. 228. The straight line A B passing through its centre, and about which it turns, is called its *axis*, and the two extremities of the axis are the *poles* of the earth, A being the north pole, and B the south pole. The line C D, crossing the axis, passes quite round the earth, and divides it into two equal parts. This is called the *equinoctial line*, or the *equator*. That part of the earth, situated north of this line, is called the *northern hemisphere*, and that part south of it, the *southern hemisphere*. The small circles E F, and G H, surrounding or including the poles, are called the *polar circles;* that surrounding the north pole is called the *arctic circle*, and that surrounding the south, the *antarctic circle*. Between these circles, there is, on each side of the equator, another circle, which marks the extent of the tropics towards the north and south, from the equator. That to the north of the equator, I K, is called the *tropic of Cancer*, and that to the south, L M, the *tropic of Capricorn*. The circle L K, extending obliquely across the two tropics, and crossing the axis of the earth, and the equator at their point of intersection, is called the *ecliptic*. This circle, as already explained, belongs rather to the heavens than the earth, being an imaginary extension of the plane of the earth's orbit in every direction towards the stars. The line in the figure shows the comparative position or direction of the ecliptic in respect to the equator, and the axis of the earth."

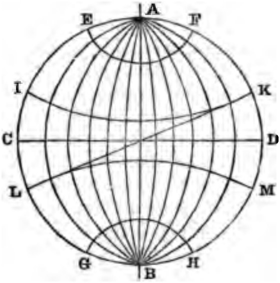

Fig. 228.

628. *Equinoctial line, or equator.*—It has been stated, in the preceding paragraph, that the diameter on which the earth turns is called its axis, the extremities of which are termed its poles. Between these poles, every point in the

earth does by its diurnal rotation describe a circle; and, because all these circles, however numerous they may be, must always keep at the same distance from the *equator*, or great circle, and run, as it were, by the side of each other, they are hence called *parallels*. The greatest of all these circles, or parallels, is that which occupies the precise middle between the poles. It is called the *equator*, because it divides the globe into two equal parts, as stated above; and *equinoctial* line, because, when the sun is in its plane, *noctes æquantur*, or the day and night are equal over the whole surface of the earth. If this equator ran along exactly under the ecliptic of the heavens, there would *always* be equal day and night over the *whole* world. But the equator *crosses* the ecliptic, as shewn in the Fig., and hence the day and night are equal only twice in the year, viz., when the sun appears in one of those two points of the ecliptic where the equator crosses it, viz., in the first point of *aries* and the first of *libra*. These two points are therefore called the *equinoctial points*, and the times of the year corresponding to them are called the *vernal* and the *autumnal equinoxes*, the one occurring in spring, the other in autumn.

629. *The tropics.*—The tropics are those circles on the earth's surface, over which the sun appears to pass directly, when he is at the greatest distance northward and southward from the equator, viz., 23½ degrees in either direction; hence, the one is called the *northern*, the other the *southern tropic*. In the former case, the sun appears to be in the beginning of cancer; in the latter, in the beginning of capricorn. The term tropic, derived from the Greek word *trepikos*, denotes a point where a *turn* is made; for the line of the ecliptic quitting the equator in the first point of *aries*, continues to rise higher northward, till it reaches the first point of *cancer*, when it *turns* to the southward; and, after again cutting the equator at the first point of *libra*, continues to descend southward till it reaches the first point of *capricorn*, when it again *turns* to the northward, and proceeds again to *aries*.

630. *Solstices.*—The solstices are closely connected with the Tropics. The term *solstice* denotes a standing still of the sun. The sun in fact *appears* to make a *stand* in the first points of cancer and capricorn, going neither northward nor southward; and as these stationary appearances occur in the summer and winter, these two seasons of the year are termed *the summer* and *winter* solstices. Hence the equinoxes and

the solstices alternate with each other, in the following order: vernal equinox, summer solstice; autumnal equinox, winter solstice.

631. *Polar circles.*—The north and south polar circles are situated at the same distance from the poles of the earth, as the tropics are from the equator, viz. 23½ degrees. These polar circles bound those portions of the earth where day or night continues during several diurnal revolutions of the earth.

632. "The lines crossing those already described, and meeting at the poles of the earth, are called *meridian lines*, or mid-day lines, for when the sun is on the meridian of a place, it is the middle of the day at that place; and, as these lines extend from north to south, the sun shines on the whole length of each, at the same time, so that it is 12 o'clock, at the same time, on every place situated on the same meridian.

633. "The spaces on the earth, between the lines extending from east to west, are called *zones*. That which lies between the tropics, from M to K, and from I to L, is called the *torrid zone*, because it comprehends the hottest portion of the earth. The spaces which extend from the tropics, north and south, to the polar circles, are called *temperate zones*, because the climates are temperate, and neither scorched with heat, like the tropics, nor chilled with cold, like the frigid zones. That lying north of the tropic of Cancer, is called the *north temperate zone*, and that south of the tropic of Capricorn, the *south temperate zone*. The spaces included within the polar circles, are called the *frigid zones*. The lines which divide the globe into two equal parts, are called the *great circles;* these are the ecliptic and the equator. Those dividing the earth into smaller parts are called the *lesser circles;* these are the lines dividing the tropics from the temperate zones, and the temperate zones from the frigid zones, &c.

634. "*Horizon.*—The horizon is distinguished into the *sensible* and *rational*. The sensible horizon is that portion of the surface of the earth which bounds our vision, or the circle around us, where the sky seems to meet the earth. When the sun rises, he appears above the sensible horizon, and when he sets, he sinks below it. The rational horizon is an imaginary line passing through the centre of the earth, and dividing it into two equal parts.

635. "*Direction of the ecliptic.*—The ecliptic, we have

already seen, is divided into 360 equal parts, called degrees. All circles, however large or small, are divided into degrees, minutes, and seconds, in the same manner as the ecliptic. The *axis* of the ecliptic is an imaginary line passing through its centre and perpendicular to its plane. The extremities of this perpendicular line, are called the *poles* of the ecliptic.

636. "If the ecliptic, or great plane of the earth's orbit, be considered on the horizon, or parallel with it, and the line of the earth's axis be inclined to the axis of this plane, or the axis of the ecliptic, at an angle of 23½ degrees, it will represent the relative positions of the orbit, and the axis of the earth. These positions are, however, merely relative, for if the position of the earth's axis be represented perpendicular to the equator, as A B, Fig. 228, then the ecliptic will cross this plane obliquely, as in that figure. But when the earth's orbit is considered as having no inclination, its axis, of course, will have an inclination, to the axis of the ecliptic, of 23½ degrees.

637. "As the orbits of all the other planets are inclined to the ecliptic, perhaps it is the most natural and convenient method to consider this as a horizontal plane, with the equator inclined to it, instead of considering the equator on the plane of the horizon, as is sometimes done.

638. "*Inclination of the earth's axis.*—The inclination of the earth's axis to the axis of its orbit never varies, but always makes an angle with it of 23½ degrees, as it moves round the sun. The axis of the earth is therefore always parallel with itself: that is, if a line be drawn through the centre of the earth, in the direction of its axis, and extended north and south, beyond the earth's diameter, the line so produced will always be parallel to the same line, or any number of lines, so drawn, when the earth is in different parts of its orbit.

639. "Suppose a rod to be fixed into the flat surface of a table, and so inclined as to make an angle with a perpendicular from the table of 23½ degrees. Let this rod represent the axis of the earth, and the surface of the table, the ecliptic. Now place on the table a lamp, and round the lamp hold a wire circle three or four feet in diameter, so that it shall be parallel with the plane of the table, and as high above it as the flame of the lamp. Having prepared a small terrestrial globe, by passing a wire through it for an axis, and letting it project a few inches each way, for the poles, take hold of the

north pole, and carry it round the circle, with the poles constantly parallel to the rod rising above the table. The rod being inclined 23½ degrees from a perpendicular, the poles and axis will be inclined in the same degree, and thus the axis of the earth will be inclined to that of the ecliptic every where in the same degree, and lines drawn in the direction of the earth's axis will be parallel to each other in any part of its orbit.

640. "This will be understood by Fig. 229, where it will be seen, that the poles of the earth, in the several positions of A, B, C, and D, being equally inclined, are parallel to each other. Supposing the lamp to represent the sun, and the wire circle, the earth's orbit, the actual position of the earth, during its annual revolution round the sun, will be comprehended, and if the globe be turned on its axis, while passing round the lamp, the diurnal or daily revolution of the earth will also be represented.

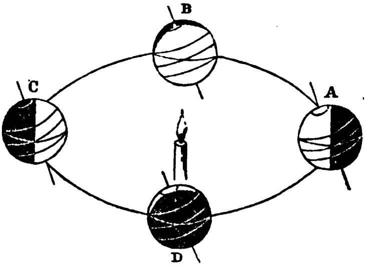

Fig. 229.

DAY AND NIGHT.

641. "Were the direction of the earth's axis perpendicular to the plane of its orbit, the days and nights would be of equal length all the year, for then just one half of the earth, from pole to pole, would be enlightened, and at the same time the other half would be in darkness. Suppose the line S O, Fig. 230, from the sun to the earth, to be the plane of the earth's orbit, and that N S is the axis of the earth perpendicular to it, then it is obvious, that exactly the same points on the earth would constantly pass through the alternate vicissitudes of day and night; for all who live on the meridian

line between N and S, which line crosses the equator at O, would see the sun at the same time, and consequently, as the earth revolves, would pass into the dark hemisphere at the same time. Hence in all parts of the globe, the days and nights would be of equal length, at any given place.

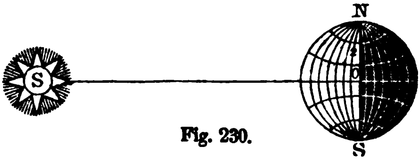

Fig. 230.

642. "Now it is the inclination of the earth's axis, as above described, which causes the lengths of the days and nights to differ at the same place at different seasons of the year; for, on reviewing the position of the globe at A, Fig. 229, it will be observed, that the line formed by the enlightened and dark hemispheres, does not coincide with the line of the axis and poles, as in Fig. 230, but that the line formed by the darkness and the light, extends obliquely across the line of the earth's axis, so that the north pole is in the light, while the south is in the dark. In the position A, therefore, an observer at the north pole would see the sun constantly, while another at the south pole would not see it at all. Hence those living in the north temperate zone, at the season of the year when the earth is at A, or in the summer, would have long days and short nights, in proportion as they approached the polar circle; while those who live in the south temperate zone, at the same time, and when it would be winter there, would have long nights and short days in the same proportion.

SEASONS OF THE YEAR.

643. "The vicissitudes of the seasons are caused by the annual revolution of the earth around the sun, together with the inclination of its axis to the plane of its orbit. It has already been explained, that the ecliptic is the plane of the earth's orbit, and is supposed to be placed on a level with the earth's horizon, and hence, that this plane is considered the standard, by which the inclination of the lines crossing the earth, and the obliquity of the orbits of the other planets, are to be estimated.

644. "The equinoctial line, or the great circle passing round

the middle of the earth, is inclined to the ecliptic, as well as the line of the earth's axis, and hence in passing round the sun, the equinoctial line intersects, or crosses the ecliptic, in two places, opposite to each other. Suppose A B, Fig. 231, to be the ecliptic, E F, the equator, and C D, the earth's axis. The ecliptic and equator are supposed to be seen edgewise, so as to appear like lines instead of circles. Now it will be understood from the figure that the inclination of the equator to the ecliptic, (or the sun's apparent annual path through the heavens,) will cause these lines, namely, the line of the equator and the line of the ecliptic, to cut, or cross each other, as the sun makes his apparent annual revolution, and that this intersection will happen twice in the year, when the earth is in the two opposite points of her orbit.

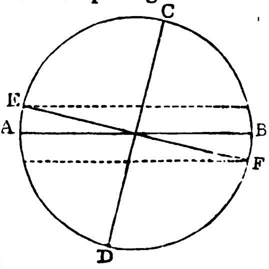

Fig. 231.

645. "These periods are on the 21st of March, and the 21st of September, in each year, and the points at which the sun is seen at these times, are called the *equinoctial* points. That which happens in September is called the *autumnai* equinox, and that which happens in March, the *vernal* equinox. At these seasons, the sun rises at 6 o'clock and sets at 6 o'clock, and the days and nights are equal in length in every part of the globe.

646. "The solstices are the points where the ecliptio and the equator are at the greatest distance from each other. The earth, in its yearly revolution, passes through each of these points. One is called the *summer*, and the other the *winter* solstice. The sun is said to enter the summer solstice on the 21st of June; and at this time, in our hemisphere, the days are longest, and the nights shortest. On the 21st of December, he enters his winter solstice, when the length of the days and nights are reversed from what they were in June before, the days being shortest, and the nights longest.

647. "Having learned these explanations, the student will be able to understand in what order the seasons succeed each other, and the reason why such changes are the effect of the earth's revolution.

648. "Suppose the earth, Fig. 232, to be in her summer

solstice, which takes place on the 21st of June. At this period she will be at A, having her north pole, N, so inclined

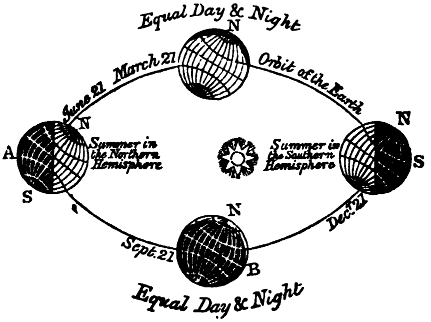

Fig. 232

towards the sun, that the whole arctic circle will be illuminated, and consequently the sun's rays will extend 23½ degrees, the breadth of the polar circles, beyond the north pole. The diurnal revolution, therefore, when the earth is at A, causes no succession of day and night at the pole, since the whole frigid zone is within the reach of his rays. The people who live within the arctic circle will, consequently, at this time, enjoy perpetual day. During this period, just the same proportion of the earth that is enlightened in the northern hemisphere, will be in total darkness in the opposite region of the southern hemisphere; so that while the people of the north enjoy perpetual day, those of the south are enveloped in perpetual night. Those who live near the arctic circle in the north temperate zone, will, during the summer, come, for a few hours, within the regions of night, by the earth's diurnal revolution; and the greater the distance from the circle, the longer will be their nights, and the shorter their days. Hence, at this season, the days will be longer than the nights everywhere between the equator and the arctic circle. At the equator, the days and nights will be equal, and between the equator and the south polar circle, the nights will be longer than the days, in the same proportion as the days are longer than the nights, from the equator to the arctic circle.

649. "As the earth moves round the sun, the line which

divides the darkness and the light gradually approaches the poles, till having performed one quarter of her yearly journey from the point A, she comes to B, about the 21st of September. At this time, the boundary of light and darkness passes through the poles, dividing the earth equally from east to west; and thus in every part of the world, the days and nights are of equal length, the sun being 12 hours alternately above and below the horizon. In this position of the earth, the sun is said to be in the *autumnal equinox.*

650. "In the progress of the earth from B to S, the light of the sun gradually reaches a little more of the antarctic circle. The days, therefore, in the northern hemisphere, grow shorter at every diurnal revolution, until the 21st of December, when the whole arctic circle is involved in total darkness. And now, the same places which enjoyed constant day in the June before, are involved in perpetual night. At this time, the sun, to those who live in the northern hemisphere, is said to be in his *winter solstice;* and then the winter nights are just as long as were the summer days, and the winter days as long as the summer nights.

651. "When the earth has completed another quarter of her annual journey, and has come to the point of her orbit opposite to where she was on the 21st of September, which happens on the 21st of March, the line dividing the light from the darkness again passes through both poles. In this position of the earth with respect to the sun, the days and nights are again equal all over the world, and the sun is said to be in his *vernal equinox.*

652. "From the vernal equinox, as the earth advances, the northern hemisphere enjoys more and more light, while the southern falls into the region of darkness, in proportion, so that the days north of the equator increase in length, until the 21st of June, at which time, the sun is again longest above the horizon, and the shortest time below it.

653. "Thus the *apparent* motion of the sun *from east to west*, is caused by the *real* motion of the earth *from west to east.* If the earth is in any point of its orbit, the sun will always seem in the opposite point in the heavens. When the earth moves one degree to the west, the sun seems to move the same distance to the east; and when the earth has completed one revolution in its orbit, the sun appears to have completed a revolution through the heavens. Hence it follows, that the ecliptic, or the apparent path of the sun

through the heavens, is the real path of the earth round the sun.

654. "It will be observed by a careful perusal of the above explanation of the seasons, and a close inspection of the figure by which it is illustrated, that the sun constantly shines on a portion of the earth equal to 90 degrees north, and 90 degrees south, from his place in the heavens, and, consequently, that he always enlightens 180 degrees, or one half the earth. If, therefore, the axis of the earth were perpendicular to the plane of its orbit, the days and nights would everywhere be equal, for as the earth performs its diurnal revolutions, there would be 12 hours day, and 12 hours night. But since the inclination of its axis is 23½ degrees, the light of the sun is thrown 23½ degrees beyond the north pole; that is, it enlightens the earth 23½ degrees farther in that direction, when the north pole is turned towards the sun, than it would, had the earth's axis no inclination. Now, as the sun's light reaches only ninety degrees north or south of his place in the heavens, so when the arctic circle is enlightened, the antarctic circle must be in the dark; for if the light reaches 23½ degrees beyond the north pole, it must fall 23½ degrees short of the south pole.

655. "As the earth travels round the sun, in his yearly circuit, this inclination of the poles is alternately *towards* and *from* him. During our winter, the north polar region is thrown beyond the rays of the sun, while a corresponding portion around the south pole enjoys the sun's light. And thus, at the poles, there are alternately six months of darkness and winter, and six months of sunshine and summer. While we, in the northern hemisphere, are chilled by the cold blasts of winter, the inhabitants of the southern hemisphere are enjoying all the delights of summer; and while we are scorched by the rays of a vertical sun in June and July, our southern neighbours are shivering with the rigours of mid-winter.

656. "At the equator, no such changes take place. The rays of the sun, as the earth passes round him, are vertical twice a year at every place between the tropics. Hence, at the equator, there are two summers and no winter, and as the sun there constantly shines on the same half of the earth in succession, the days and nights are always equal, there being 12 hours of light, and 12 of darkness.

657. "MOTION OF THE EARTH.—The motion of the earth

round the sun, is at the rate of 68,000 miles in an hour, while its motion on its own axis, at the equator, is at the rate of about 1042 miles in the hour. The equator, being that part of the earth most distant from its axis, the motion there is more rapid than towards the poles, in proportion to its greater distance from the axis of motion. See Fig. 13, § 83.

658. "The method of ascertaining the velocity of the earth's motion, both in its orbit and round its axis, is simple, and easily understood; for by knowing the diameter of the earth's orbit, its circumference is readily found, and as we know how long it takes the earth to perform her yearly circuit, we have only to calculate what part of her journey she goes through in an hour. By the same principle, the hourly rotation of the earth is as readily ascertained.

659. "We are insensible to these motions, because not only the earth, but the atmosphere, and all terrestrial things, partake of the same motion, and there is no change in the relation of objects in consequence of it. If we look out at the window of a steam-boat, when it is in motion, the boat will seem to stand still, while the trees and rocks on the shore appear to pass rapidly by us. This deception arises from our not having any object with which to compare this motion, when shut up in the boat; for then every object around us keeps the same relative position. And so, in respect to the motion of the earth, having nothing with which to compare its movement, except the heavenly bodies, when the earth moves in one direction, these objects appear to move in the contrary direction.

CAUSES OF THE HEAT AND COLD OF THE SEASONS.

660. "We have seen that the earth revolves round the sun in an elliptical orbit, of which the sun is one of the foci, and consequently, that the earth is nearer to him, in one part of her orbit than in another. From the great difference we experience between the heat of summer and that of winter, we should be led to suppose that the earth must be much nearer the sun in the hot season than in the cold. But when we come to inquire into this subject, and to ascertain the distance of the sun at different seasons of the year, we find that the great source of heat and light is nearest us during the cold of winter, and at the greatest distance during the heat of summer.

661. "It has been explained, under the article *Optics*, that

the angle of vision depends on the distance at which a body of given dimensions is seen. Now, on measuring the angular dimension of the sun, with accurate instruments, at different seasons of the year, it has been found that his dimensions increase and diminish, and that these variations correspond exactly with the supposition, that the earth moves in an elliptical orbit. If, for instance, his apparent diameter be taken in March, and then again in July, it will be found to have diminished, which diminution is only to be accounted for, by supposing that he is at a greater distance from the observer in July than in March. From July, his angular diameter gradually increases, till January, when it again diminishes, and continues to diminish, until July. By many observations, it is found, that the greatest apparent diameter of the sun, and therefore his least distance from us, is in January, and his least diameter, and therefore his greatest distance, is in July. The actual difference is about three millions of miles, the sun being that distance further from the earth in July than in January. This, however, is only about one sixtieth of his mean distance from us, and the difference we should experience in his heat, in consequence of this difference of distance, will therefore be very small. Perhaps the effect of his proximity to the earth may diminish, in some small degree, the severity of winter.

662. "The heat of summer, and the cold of winter, must therefore arise from the difference in the meridian altitude of the sun, and in the time of his continuance above the horizon. In summer, the solar rays fall on the earth, in nearly a *perpendicular* direction, and his powerful heat is then constantly accumulated by the long days and short nights of the season. In winter, on the contrary, the solar rays fall so *obliquely* on the earth, as to produce little warmth, and the small effect they do produce during the short days of that season, is almost entirely destroyed by the long nights which succeed. The difference between the effects of perpendicular and oblique rays, seems to depend, in a great measure, on the different extent of surface over which they are spread. When the rays of the sun are made to pass through a convex lens, the heat is increased, because the number of rays which naturally covered a large surface, are then made to cover a smaller one, so that the power of the glass depends on the number of rays thus brought to a focus. If, on the contrary, the rays of the sun are suffered to pass through a

concave lens, their natural heating power is diminished, because they are dispersed, or spread over a wider surface than before.

663. "Now, to apply these different effects to the summer and winter rays of the sun, let us suppose that the rays falling perpendicularly on a given extent of surface, impart to it a certain degree of heat; then it is obvious, that if the same number of rays be spread over twice that extent of surface, their heating power would be diminished in proportion, and that only half the heat would be imparted. This is the effect produced by the sun's rays in the winter. They fall so obliquely on the earth, as to occupy nearly double the space that the same number of rays do in the summer. This is illustrated by Fig. 233, where the number of rays, both in winter and summer, are supposed to be the same. But, it will be observed, that the winter rays, owing to their oblique direction, are spread over nearly twice as much surface as those of summer.

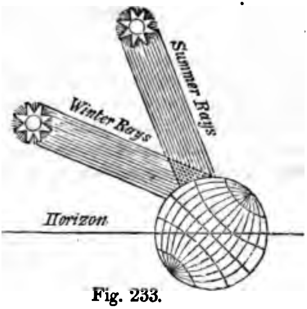

Fig. 233.

664. It may, however, be remarked, that the hottest season is not usually at the exact time of the year, when the sun is most vertical, and the days the longest, as is the case towards the end of June, but some time afterwards, as in July and August. To account for this, it must be remembered, that when the sun is nearly vertical, the earth accumulates more heat by day than it gives out at night, and that this accumulation continues to increase after the days begin to shorten, and, consequently, the greatest elevation of temperature is some time after the longest days. For the same reason, the thermometer generally indicates the greatest degree of heat at two or three o'clock on each day, and not at twelve o'clock, when the sun's rays are most powerful.

FIGURE OF THE EARTH.

665. Astronomers have proved that all the planets, together with their satellites, have the shape of the sphere, or globe, and hence, by analogy, there was every reason to suppose,

that the earth would be found of the same shape; and several phenomena tend to prove, beyond all doubt, that this is its form. The figure of the earth is not, however, exactly that of a globe, or ball, because its diameter is about 34 miles less from pole to pole, than it is at the equator. But that its general figure is that of a sphere, or ball, is proved by many circumstances.

666.' "When a person is at sea, or standing on the seashore, the first part of a ship seen at a distance, is its mast. As the vessel advances, the mast rises higher and higher above the horizon, and finally the hull, and whole ship, become visible. Now, were the earth's surface an exact plane, no such appearance would take place, for we should then see the hull long before the mast or rigging, because it is much the largest object. It will be plain by Fig. 234, that were the ship, A, elevated, so that the hull should be on a horizontal line with the eye, the whole ship would be visible, instead of the topmast, there being no reason, except the convexity of the earth, why the whole ship should not be visible at A, as well as at B. We know, for the same reason, that in passing over a hill, the tops of the trees are seen, before we can discover the ground on which they stand; and that when a man approaches from the opposite side of a hill, his head is seen before his feet."

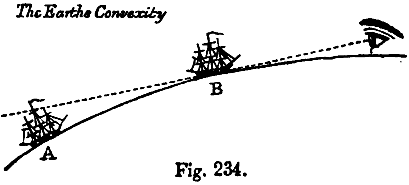

Fig. 234.

667. "If we sail out of sight of land, whether we stand on the deck of the ship, or climb the mast, we see the surface of the sea—not losing itself in distance and mist, but terminated by a sharp, clear, well-defined line, or *offing*, as it is called, which runs all round us in a circle, having our station for its centre. That this line is really a circle, we conclude, first, from the perfect apparent similarity of all its parts; and, secondly, from the fact of all its parts appearing at the same distance from us, and that, evidently, a moderate one; and, thirdly, from this, that its apparent *diameter*, measured with

an instrument called the *dip sector*, is the same (except under some singular atmospheric circumstances, which produce a temporary distortion of its outline,) in whatever direction the measure is taken—properties which belong only to the circle among geometrical figures. If we ascend a high eminence on a plain (for instance, one of the Egyptian pyramids), the same holds good.

668. "Masts of ships, however, and the edifices erected by man, are trifling eminences, compared to what nature itself affords: Etna, Teneriffe, Mowna Roa, are eminences from which no contemptible *aliquot* part of the whole earth's surface can be seen; but from these again—in those few and rare occasions when the transparency of the air will permit the real boundary of the horizon, the true sea-line, to be seen—the very same appearances are witnessed, but with this remarkable addition, viz., that the angular *diameter* of the visible area, as measured by the dip sector, is materially *less* than at a lower level; or, in other words, that the *apparent size* of the earth has sensibly diminished as we have receded from its surface, while yet the *absolute quantity* of it seen at once has been increased. The same appearances are observed universally, in every part of the earth's surface visited by man. Now, the figure of a body, which, however seen, always appears *circular*, can be no other than a sphere or globe."—*Herschel's Astronomy.*

669. "It is a well known fact also, that navigators have set out from a particular port, and by sailing continually westward, have passed around the earth, and again reached the port from which they sailed. This could never happen, were the earth an extended plane, since then the longer the navigator sailed in one direction, the further he would be from home.

670. "Another proof of the spheroidal form of the earth, is the figure of its shadow on the moon, during eclipses, which shadow is always bounded by a circular line.

671. "These circumstances prove, beyond all doubt, that the form of the earth is globular, but that it is not an exact sphere; and that it is depressed or flattened at the poles, is shown by the difference in the lengths of pendulums vibrating seconds at the poles, and at the equator.

672. "Under the article *pendulum*, it was shown that its vibrations depend on the attraction of gravitation, and that as the centre of the earth is the centre of this attraction, so

the nearer this instrument is carried to that point, the stronger will be the attraction, and consequently the more frequent its vibrations. From a great number of experiments, it has been found that a pendulum, which vibrates seconds at the equator, has its number of vibrations increased, when it is carried towards the poles; and as its number of vibrations depends upon its length, a clock which keeps accurate time at the equator, must have its pendulum lengthened at the poles. And so, on the contrary, a clock going correctly at, or near the poles, must have its pendulum shortened, to keep exact time at the equator. Hence the force of gravity is greatest at the poles, and least at the equator.

673. "The manner in which the figure of the earth differs from that of a sphere, is represented by Fig. 235, where N is the north pole, and S the south pole, the line from one of these points to the other, being the axis of the earth, and the line crossing this, the equator. It will be seen by this figure, that the surface of the earth, at the poles, is nearer its centre, than the surface at the equator. The actual difference between the polar and equatorial diameters is in the proportion of 300 to 301. The earth is therefore called an *oblate spheroid*, the word oblate signifying the reverse of oblong, or shorter in one direction than in another.

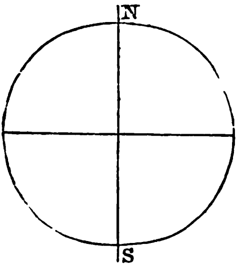

Fig. 235.

674. "The compression of the earth at the poles, and the consequent accumulation of matter at the equator, is probably the effect of its diurnal revolution, while it was in a soft or plastic state. If a ball of soft clay, or putty, be made to revolve rapidly, by means of a stick passed through its centre, as an axis, it will swell out in the middle, or equator, and be depressed at the poles, assuming the precise figure of the earth. This figure is the natural and obvious consequence of the *centrifugal force*, which operates to throw the matter off, in proportion to its distance from the axis of motion, and the rapidity with which the ball is made to revolve. The parts about the equator would therefore tend to fly off, and leave the other parts, in consequence of the centrifugal force, while those about the poles, being nearer the centre of

motion, would receive a much smaller impulse. Consequently the ball would swell, or bulge out at the equator, which would produce a corresponding depression at the poles.

675. "The weight of a body at the poles is found to be greater than at the equator, not only because the poles are nearer the centre of the earth than the equator, but because the centrifugal force there tends to lessen its gravity. The wheels of machines which revolve with the greatest rapidity are made in the strongest manner, otherwise they will fly in pieces, the centrifugal force not only overcoming the gravity, but the cohesion of their parts.

676. "It has been found by calculation, that if the earth turned over once in 84 minutes and 43 seconds, the centrifugal force at the equator would be equal to the power of gravity there, and that bodies would entirely lose their weight. If the earth revolved more rapidly than this, all the buildings, rocks, mountains, and men, at the equator, would not only lose their weight, but would fly from the earth, as mud does from a carriage-wheel in rapid motion.

SOLAR AND SIDEREAL TIME.

677. "The stars appear to go round the earth in 23 hours, 56 minutes, and 4 seconds, while the sun appears to perform the same revolution in 24 hours, so that the stars gain 3 minutes and 56 seconds upon the sun every day. In a year, this amounts to a day, or to the time taken by the earth to perform one diurnal revolution. It therefore happens, that when time is measured by the stars, there are 366 days in the year, or 366 diurnal revolutions of the earth; while, if measured by the sun from one meridian to another, there are only 365 whole days in the year. The former are called the *sidereal*, and the latter *solar* days.

678. "To account for this difference, we must remember that the earth, while she performs her daily revolutions, is constantly advancing in her orbit, and that, therefore, at 12 o'clock to-day she is not precisely at the same place in respect to the sun, that she was at 12 o'clock yesterday, or will be to-morrow. But the fixed stars are at such an amazing distance from us, that the earth's orbit, in respect to them, is but a point; and, therefore, as the earth's diurnal motion is perfectly uniform, she revolves from any given star to the same star again, in exactly the same period of absolute time. The orbit of the earth, were it a solid mass, instead of an

imaginary circle, would have no appreciable length or breadth, when seen from a fixed star, and therefore, whether the earth performed her diurnal revolutions at a particular station, or while passing round in her orbit, would make no appreciable difference with respect to the star. Hence the same star, at every complete daily revolution of the earth, appears precisely in the same direction at all seasons of the year. The moon, for instance, would appear at exactly the same point, to a person who walks round a circle of a hundred yards in diameter, and for the same reason a star appears in the same direction from all parts of the earth's orbit, though 190 millions of miles in diameter.

679. "If the earth had only a diurnal motion, her revolution, in respect to the sun, would coincide exactly with the same revolution in respect to the stars; but while she is making one revolution on her axis towards the east, she advances in the same direction about one degree in her orbit, so that to bring the same meridian towards the sun, she must make a little more than one entire revolution. To make this

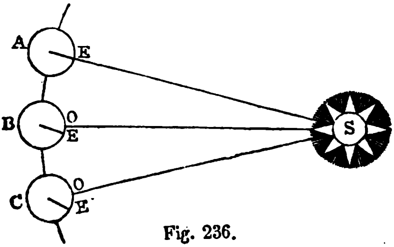

Fig. 236.

plain, suppose the sun, S, Fig. 236, to be exactly on a meridian line marked at E, on the earth A, on a given day. On the next day, the earth, instead of being at A, as on the day before, advances in its orbit to B, and in the meantime having completed her revolution, in respect to a star, the same meridian line is not brought under the sun, as on the day before, but falls short of it, as at E, so that the earth has to perform more than a revolution, by the distance from E to O, in order to bring the same meridian again under the sun. So on the next day, when the earth is at C, she must again complete more than two revolutions, since leaving A, by the space from E to O, before it will again be noon at E.

680. "Thus, it is obvious, that the earth must complete one revolution, and a portion of a second revolution, equal to the space she has advanced in her orbit, in order to bring the same meridian back again to the sun. This small portion of a second revolution amounts daily to the 365th part of her circumference, and therefore, at the end of the year, to one entire rotation, and hence in 365 days, the earth actually turns on her axis 366 times. Thus, as one complete rotation forms a sidereal day, there must, in the year, be one sidereal, more than there are solar days, one rotation of the earth, with respect to the sun, being lost, by the earth's yearly revolution. The same loss of a day happens to a traveller, who, in passing round the earth towards the west, reckons his time by the rising and setting of the sun. If he pass round towards the east, he will gain a day for the same reason.

EQUATION OF TIME.

681. "As the motion of the earth about its axis is perfectly uniform, the sidereal days, as we have already seen, are exactly of the same length, in all parts of the year. But as the orbit of the earth, or the apparent path of the sun, is inclined to the earth's axis, and as the earth moves with different velocities in different parts of its orbit, the solar, or natural days, are sometimes greater and sometimes less than 24 hours, as shown by an accurate clock. The consequence is, that a true sun dial, or noon mark, and a true time piece, agree with each other only a few times in a year. The difference between the sun dial and clock, thus shown, is called the *equation of time.* The difference between the sun and a well regulated clock, thus arises from two causes, the inclination of the earth's axis to the ecliptic, and the elliptical form of the earth's orbit.

682. "That the earth moves in an ellipse, and that its motion is more rapid sometimes than at others, as well as that the earth's axis is inclined to the ecliptic, have already been explained and illustrated. It remains, therefore, to show how these two combined causes, the elliptical form of the orbit, and the inclination of the axis, produce the disagreement between the sun and clock. In this explanation, we must consider the sun as moving around the ecliptic, while the earth revolves on her axis.

683. "*Equal,* or *mean* time is that which is reckoned by

a clock, supposed to indicate exactly 24 hours, from 12 o'clock on one day, to 12 o'clock on the next day. *Apparent* time is that which is measured by the apparent motion of the sun in the heavens, as indicated by a meridian line, or sun dial.

684. "Were the earth's orbit a perfect circle, and her axis perpendicular to the plane of this orbit, the days would be of a uniform length, and there would be no difference between the clock and the sun: both would indicate 12 o'clock at the same time, on every day in the year. But on account of the inclination of the earth's axis to the ecliptic, unequal portions of the sun's apparent path through the heavens will pass any meridian in equal times. This may be readily explained to the pupil, by means of an artificial globe; but perhaps it will be understood by the following diagram:—

685. "Let A N B S, Fig. 237, be the concave of the heavens, in the centre of which is the earth. Let the line A B, be the equator, extending through the earth and the heavens,

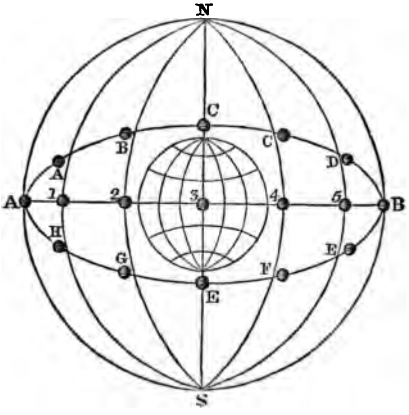

Fig. 237.

and let A, a, b, C, c, and d, be the ecliptic, or the apparent path of the sun through the heavens. Also, let A, 1, 2, 3, 4, 5, be equal distances on the equator, and A, a, b, C, c, and d, equal portions of the ecliptic, corresponding with A 1, 2, 3, 4, and 5. Now we will suppose, that there are two suns, namely, a false, and a real one; that the false one passes through the celestial equator, which is only an extension of the earth's equator, to the heavens; while the real sun has an apparent revolution through the ecliptic; and that they both start from the point A, at the same instant. The false sun is supposed to pass through the celestial equator in the same time that the real one passes through the ecliptic, but not through the same meridians at the same time, so that the false sun arrives at the points 1, 2, 3, 4, and 5, at the time when the real sun arrives at the points A, B, C, and C.

686. "When the two suns were at A, the starting point, they were both on the same meridian, but when the fictitious sun comes to 1, and the real sun to A, they are not in the same meridian, but the real sun is westward of the fictitious one, the real sun being at A while the false sun is on the meridian 1; consequently, as the earth turns on its axis from west to east, any particular place will come under the sun's real meridian, sooner than under the fictitious sun's meridian; that is, it will be 12 o'clock by the true sun, before it is 12 o'clock by the false sun, or by a true clock; but were the true sun in place of the false one, the sun and clock would agree. While the true sun is passing through that quarter of his orbit, from A to C, and the fictitious sun from 1 to 3, it will always be noon by the true sun before it is noon by the false sun, and during this period, the sun will be *faster* than the clock.

687. "When the true sun arrives at C, and the false one at 3, they are both on the same meridian, and the sun and clock agree. But while the real sun is passing from C to B, and the false one from 3 to B, any meridian comes later under the true sun than it does under the false, and then it is noon by the sun after it is noon by the clock, and the sun is then said to be *slower* than the clock. At B, both suns are again on the same meridian, and then again the sun and clock agree.

688. "We have thus followed the real sun through one half of his *true apparent* place in the heavens, and the false one through half the celestial equator, and have seen that the two suns, since leaving the point A, have been only twice on the same meridian at the same time. It has been supposed that the two suns passed through equal arcs in equal times, the real sun through the ecliptic, and the false one through the equator. The place of the false sun may be considered

as representing the place where the real sun would be, in case the earth's axis had no inclination, and consequently it agrees with the clock every 24 hours. But the true sun, as he passes round in the ecliptic, comes to the same meridian, sometimes sooner, and sometimes later, and in passing around the other half of the ecliptic, or in the other half year, the same variations succeed each other.

689. "The two suns are supposed to depart from the point A, on the 20th of March, at which time the sun and clock coincide. From this time, the sun is *faster* than the clock, until the two suns come together at the point C, which is on the 21st of June, when the sun and clock again agree. From this period the sun is *slower* than the clock, until the 23d of September, and *faster* again until the 21st of December, at which time they agree as before.

690. "We have thus seen how the inclination of the earth's axis, and the consequent obliquity of the equator to the ecliptic, cause the sun and clock to disagree, and on what days they would coincide, provided no other cause interfered with their agreement. But although the inclination of the earth's axis would bring the sun and clock together on the above-mentioned days, yet this agreement is counteracted by another cause, which is the elliptical form of the earth's orbit, and though the sun and clock do agree four times in the year, it is not on any of the days above mentioned.

691. "It has been shown by Fig. 227, that the earth moves more rapidly in one part of its orbit than in another. When it is nearest the sun, which is in the winter, its velocity is greater than when it is most remote from him, as in the summer. Were the earth's orbit a perfect circle, the sun and clock would coincide on the days above specified, because then the only disagreement would arise from the inclination of the earth's axis. But since the earth's distance from the sun is constantly changing, her rate of velocity also changes, and she passes through unequal portions of her orbit in equal times. Hence, on some days, she passes through a greater portion of it than on others, and thus this becomes another cause of the inequality of the sun's apparent motion.

692. "The elliptical form of the earth's orbit would prevent the coincidence of the sun and clock at all times, except when the earth is at the greatest distance from the sun, which happens on the 1st of July, and when she is at the least distance from him, which happens on the 1st of January.

As the earth moves faster in the winter than in the summer, from this cause, the sun would be faster than the clock from the 1st of July to the 1st of January, and then slower than the clock from the 1st of January to the 1st of July.

693. "We have now explained, separately, the two causes which prevent the coincidence of the sun and clock. By the first cause, which is the inclination of the earth's axis, they would agree four times in the year; and by the second cause, the irregularity of the earth's motion, they would coincide only twice in the year. Now, these two causes counteract the effects of each other, so that the sun and clock do not coincide on any of the days, when either cause, taken singly, would make an agreement between them. The sun and clock, therefore, are together, only when the two causes balance each other; that is, when one cause so counteracts the other, as to make a mutual agreement between them. This effect is produced four times in the year; namely, on the 15th of April, 15th of June, 31st of August, and 24th of December. On these days, the sun, and a clock keeping exact time, coincide, and on no others. The greatest difference between the sun and clock, or between the apparent and mean time, is 16½ minutes, which takes place about the 1st of November.

PRECESSION OF THE EQUINOXES.

694. "A *tropical* year is the time it takes the sun to pass from one equinox, or tropic, to the same tropic, or equinox, again. A *sidereal* year is the time it takes the sun to perform his apparent annual revolution, from a fixed star, to the same fixed star again.

695. "Now it has been found that these two complete revolutions are not finished in exactly the same time, but that it takes the sun about 20 minutes longer to complete his apparent revolution in respect to the *star*, than it does in respect to the *equinox*, and hence the *sidereal year* is about 20 minutes longer than the *tropical year*. The revolution of the earth from equinox to equinox, again, therefore, *precedes* its complete revolution in the ecliptic by about 20 minutes, for the absolute revolution of the earth is measured by its return to the fixed star, and not by the return of the sun to the same equinoctial point. This apparent falling back of the equinoctial point, so as to make the time when it meets the sun *precede* the time when the earth makes its complete

revolution in respect to the star, is called the *precession of the equinoxes.*

696. "The distance which the sun thus gains upon the fixed star, or the difference between the sun and star, when the sun has arrived at the equinoctial point, amounts to 50 seconds of a degree, thus making the equinoctial point recede 50 seconds of a degree, (when measured by the signs of the zodiac,) westward, every year, contrary to the sun's annual progressive motion in the ecliptic.

697. "To illustrate this by a figure, suppose S, Fig. 238, to be the sun, E the earth, and O a fixed star, all in a straight line with respect to each other. Let it be supposed that this opposition takes place on the 21st of March, at the vernal equinox, and that at that time the earth is exactly between the sun and the star. Now when the earth has performed a complete revolution around its orbit B, A, as measured by the star, she will arrive at precisely the same point where she now is. But it is found that when the earth comes to the same equinoctial point, the next year, she has not gone her complete revolution in respect to the star; the equinoctial point having fallen back with respect to the star, during the year, from E to E′, so that the earth, after having completed her revolution, in respect to the equinox, has yet to pass the space from E′ to E, to complete her revolution in respect to the star.

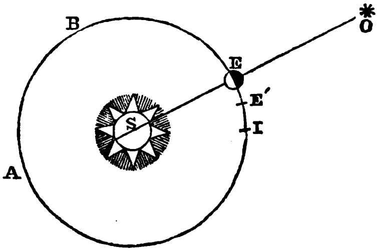

Fig. 238.

698. "The space from E to E′, being 50 seconds of a degree, and the equinoctial point falling this space every year short of the place where the sun and this point agreed the year before, it is obvious, that on the next revolution of the earth, the equinox will not be found at E, but at I, so that

the earth, having completed her second revolution in respect to the sun when at I, will still have to pass from I to E, before she completes another revolution in respect to the star.

699. "The precession of the equinoxes, being 50 seconds of a degree, every year, contrary to the sun's apparent motion, or about 20 minutes, in time, short of the point where the sun and equinoxes coincided the year before, it follows, that the fixed stars, or those in the sign of the zodiac, move forward every year 50 seconds, with respect to the equinoxes.

700. "In consequence of this precession, in 2160 years, those stars which now appear in the beginning of the sign Aries, for instance, will then appear in the beginning of Taurus, having moved forward one whole sign, or 30 degrees, with respect to the equinoxes, or the equinoxes having gone backwards 30 degrees, with respect to the stars. In 12,960 years, or 6 times 2160 years, therefore, the stars will appear to have moved forward one-half of the whole circle of the heavens, so that those which now appear in the first degree of the sign Aries, will then be in the opposite point of the zodiac, and, therefore, in the first degree of Libra. And in 12,600 years more, because the equinoxes will have fallen back the other half of the circle, the stars will appear to have gone forward from Libra to Aries, thus completing the whole circle of the zodiac. Thus, in about 26,000 years, the equinox will have gone backwards a whole revolution around the axis of the ecliptic, and the stars will appear to have gone forward the whole circle of the zodiac.

701. "The discovery of the precession of the equinoxes has thrown much light on ancient astronomy and chronology, by showing an agreement between ancient and modern observations, concerning the places of the signs of the zodiac, not to be reconciled in any other manner. A complete explanation of the cause which occasions the precession of the equinoxes, would require the aid of the most abstruse mathematics, and therefore cannot be properly introduced here. The cause itself may, however, be stated in a few words. It has already been explained that the revolution of the earth round its axis has caused an excess of matter to be accumulated at the equator, and hence, that the equatorial is greater than the polar diameter by 26 miles. Now the attraction of the sun and moon on this accumulated matter at the equator has the effect of slowly turning the earth about the axis of

the ecliptic, and thus causing the precession of the equinoxes.

THE MOON.

702. The moon is of about the fiftieth part of the bulk of the earth; the mean or average distance of its centre from that of the earth is about 237,000 miles. "This distance," observes Sir J. Herschel, "great as it is, is little more than one-fourth of the diameter of the sun's body, so that the whole globe of the sun would nearly twice include the whole orbit of the moon; a consideration wonderfully calculated to raise our ideas of that stupendous luminary!"

703. "While the earth revolves round the sun, the moon revolves round the earth, completing her revolution once in 27 days, 7 hours, and 43 minutes, and at the distance of 240,000 miles from the earth. The period of the moon's change, that is, from new moon to new moon again, is 29 days, 12 hours, and 44 minutes.

704. "The time of the moon's revolution round the earth is called her *periodical* month; and the time from change to change is called her *synodical* month. If the earth had no annual motion, these two periods would be equal, but because the earth goes forward in her orbit, while the moon goes round the earth, the moon must go as much farther, from change to change, to make these periods equal, as the earth goes forward during that time, which is more than the twelfth part of her orbit, there being more than twelve lunar periods in the year.

705. "These two revolutions may be familiarly illustrated by the motions of the hour and minute hands of a watch. Let us suppose the 12 hours marked on the dial plate of a watch to represent the 12 signs of the zodiac through which the sun seems to pass in his yearly revolution, while the hour hand of the watch represents the sun, and the minute hand the moon. Then, as the hour hand goes round the dial plate once in 12 hours, so the sun apparently goes round the zodiac once in 12 months; and as the minute hand makes 12 revolutions to one of the hour hand, so the moon makes 12 revolutions to one of the sun. But the moon, or minute hand, must go more than once round, from any point on the circle, where it last came in conjunction with the sun, or hour hand, to overtake it again, since the hour hand will have moved forward of the place where it

was last overtaken, and consequently the next conjunction must be forward of the place where the last happened. During an hour, the hour hand describes the twelfth part of the circle, but the minute hand has not only to go round the whole circle in an hour, but also such a portion of it, as the hour hand has moved forward since they last met. Thus, at 12 o'clock, the hands are in conjunction; the next conjunction is 5 minutes 27 seconds past I o'clock; the next, 10 min. 54 sec. past II o'clock; the 3d, 16 min. 21 sec. past III; the 4th, 21 min. 49 sec. past IV; the 5th, 27 min. 10 sec. past V; the 6th, 32 min. 43 sec. past VI; the 7th, 38 min. 10 sec. past VII; the 8th, 43 min. 38 sec. past VIII; the 9th, 49 min. 5 sec. past IX; the 10th, 54 min. 32 sec. past X; and the next conjunction is at XII.

706. " Now although the moon passes around the earth in 27 days 7 hours and 43 minutes, yet her change does not take place at the end of this period, because her changes are not occasioned by her revolutions alone, but by her coming periodically into the same position in respect to the sun. At her change, she is in conjunction with the sun, when she is not seen at all, and at this time astronomers call it *new moon*, though generally, we say it is new moon two days afterwards, when a small part of her face is to be seen. The reason why there is not a new moon at the end of 27 days, will be obvious, from the motions of the hands of a watch; for we see that more than a revolution of the minute hand is required to bring it again in the same position with the hour hand, by about the twelfth part of the circle.

707. "The same principle is true in respect to the moon; for as the earth advances in its orbit, it takes the moon 2 days 5 hours and 1 minute longer to come again in conjunction with the sun, than it does to make her monthly revolution round the earth; and this 2 days 5 hours and 1 minute being added to 27 days 7 hours and 43 minutes, the time of the periodical revolution, makes 29 days 12 hours and 44 minutes, the period of her synodical revolution.

708. " The moon always presents the same side, or face, towards the earth, and hence it is evident that she turns on her axis but once, while she is performing one revolution round the earth, so that the inhabitants of the moon have but one day, and one night, in the course of a lunar month. One half of the moon is never in the dark, because when this half is not enlightened by the sun, a strong light is re-

flected to her from the earth, during the sun's absence. The other half of the moon enjoys alternately two weeks of the sun's light, and two weeks of total darkness.

709. "The moon is a globe, like our earth, and, like the earth, shines only by the light reflected from the sun; therefore, while that half of her which is turned towards the sun is enlightened, the other half is in darkness. Did the moon shine by her own light, she would be constantly visible to us, for then, being an orb, and every part illuminated, we should see her constantly full and round, as we do the sun.

710. "One of the most interesting circumstances to us, respecting the moon, is the constant changes which she undergoes, in her passage around the earth. When she first appears, a day or two after her change, we can see only a small portion of her enlightened side, which is in the form of a crescent; and at this time she is commonly called *new moon.* From this period, she goes on increasing, or showing more and more of her face every evening, until at last she becomes round, and her face fully illuminated. She then begins again to decrease, by apparently losing a small section of her face, and the next evening another small section from the same part, and so on, decreasing a little every day, until she entirely disappears; and having been absent a day or two, re-appears, in the form of a crescent, or new moon, as before. When the moon disappears, she is said to be in *conjunction*, that is, she is in the same direction from us with the sun. When she is full, she is said to be in *opposition*, that is, she is in that part of the heavens opposite to the sun, as seen by us.

711. "The different appearances of the moon from *new* to *full*, and from full to *change*, are owing to her presenting different portions of her enlightened surface towards us at different times. These appearances are called the *phases* of the moon, and are easily accounted for, and understood, by the following figure. Let S, Fig. 239, be the sun, E the earth, and A, B, C, D, E, the moon in different parts of her orbit. 1. Now when the moon changes, or is in conjunction with the sun, as at A, her dark side is turned towards the earth, and she is invisible, as represented at A'. The sun always shines on one half of the moon, in every direction, as represented at A and B, on the inner circle; but we at the earth can see only such portions of the enlightened half as

are turned towards us. 2. After her change, when she has moved from A to B, a small part of her illuminated side comes in sight, and she appears horned, as at B′, and is then called the *new* moon. 3. When she arrives at C, several days afterwards, one half of her disk is visible, and she appears as at C′, her appearance being the same in both circles. At this point she is said to be in her *first quarter*, because she has passed through a quarter of her orbit, and is 90 degrees from the place of her conjunction with the sun. 4. At D, she shows us still more of her enlightened side, and is then said to appear *gibbous*, as at D′. 5. When she comes to E, her whole enlightened side is turned towards the earth, and she appears in all the splendour of a *full* moon. During the other half of her revolution, she daily shows less and less of her illuminated side, until she again becomes invisible by her conjunction with the sun. Thus, in passing from her conjunction A′, to her full E′, the moon appears every day to increase, while in going from her full to her conjunction again, she appears to us constantly to decrease, but as seen from the sun, she appears always full.

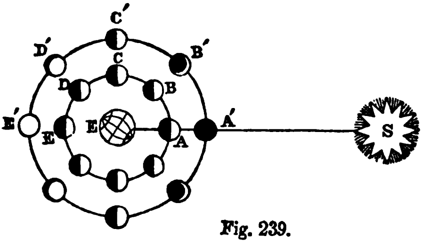

Fig. 239.

712. "*How the earth appears at the moon.*—The earth, seen by the inhabitants of the moon, exhibits the same phases that the moon does to us, but in a contrary order. When the moon is in her conjunction, and consequently invisible to us, the earth appears full to the people of the moon, and when the moon is full to us, the earth is dark to them.

713. "The earth appears thirteen times larger to the inhabitants of the moon than the moon does to us. As the moon always keeps the same side towards the earth, and turns on her axis only as she moves round the earth, we never see her opposite side. Consequently, the inhabitants of the moon

who live on the opposite side to us never see the earth at all. To those who live on the middle of the side next to us, our earth is always visible, and directly over head, turning on its axis nearly thirty times as rapidly as the moon, for she turns only once in about thirty days. A lunar astronomer, who should happen to live directly opposite to that side of the moon, which is next to us, would have to travel a quarter of the circumference of the moon, or about 1500 miles, to see our earth above the horizon, and if he had the curiosity to see such a glorious orb, in its full splendour over his head, he must travel 3000 miles. But if his curiosity equalled that of the terrestrials, he would be amply compensated by beholding so glorious a nocturnal luminary, a moon thirteen times as large as ours.

714. "That the earth shines upon the moon as the moon does upon us, is proved by the fact that the outline of her whole disk may be seen, when only a part of it is enlightened by the sun. Thus when the sky is clear, and the moon only two or three days old, it is not uncommon to see the brilliant new moon, with her horns enlightened by the sun, and at the same time, the old moon faintly illuminated by reflection from the earth. This phenomenon is sometimes called 'the old moon in the new moon's arms.'

715. "It was a disputed point among former astronomers, whether the moon has an atmosphere; but the more recent discoveries have decided that she has an atmosphere, though there is reason to believe that it is much less dense than ours.

716. "*Surface of the moon.*—When the moon's surface is examined through a telescope, it is found to be wonderfully diversified, for besides the dark spots perceptible to the naked eye, there are seen extensive valleys, and long ridges of highly elevated mountains. Some of these mountains, according to Dr Herschel, are four miles high, while hollows more than three miles deep, and almost exactly circular, appear excavated on the plains. Astronomers have been at vast labour to enumerate, figure, and describe, the mountains and spots on the surface of the moon, so that the latitude and longitude of about 100 spots have been ascertained, and their names, shapes, and relative positions given. A still greater number of mountains have been named, and their heights and the length of their bases detailed.

717. "The deep caverns, and broken appearance of the moon's surface, long since induced astronomers, to believe

that such effects were produced by volcanoes, and more recent discoveries have seemed to prove that this suggestion was not without foundation. Dr Herschel saw, with his telescope, what appeared to him three volcanoes in the moon, two of which were nearly extinct, but the third was in the actual state of eruption, throwing out fire, or other luminous matter, in vast quantities. It was formerly believed that several large spots, which appeared to have plain surfaces, were seas, or lakes, and that a part of the moon's surface was covered with water, like that of our earth. But it has been found, on closely observing these spots, when they were in such a position as to reflect the sun's light to the earth, had they been water, that no such reflection took place. It has also been found that, when these spots were turned in a certain position, their surfaces appeared rough and uneven, a certain indication that they are not water. These circumstances, together with the fact that the moon's surface is never obscured by mist or vapour, arising from the evaporation of water from her surface, have induced astronomers to believe that the moon has neither seas, lakes, nor rivers, and indeed that no water exists there."

718. *Harvest moon; Hunters' moon.*—Twice in the year the moon rises almost at the same hour during a week. This occurs in September or October, and in March or April; in the former case, the moon is termed the *harvest moon*, in the latter, the *hunters' moon*. The following is an explanation of these phenomena, divested of technicalities. The moon moves nearly to the same distance from the sun every day, but it moves in a path the one-half of which is much nearer the north than the other; and this is the case also with the apparent annual path of the sun, that luminary appearing much nearer to the north in summer than in winter. Thus, when the moon is moving northward at the most rapid rate, it escapes from the horizon northward, and rises earlier; and when it moves southward at the most rapid rate, it approaches the horizon and sets earlier. The full moon can be in the former position only in September or October, and in the latter in March or April; and thus the *harvest* and *hunters'* moons are occasional.

THE SATELLITES.

719. *Satellites of Jupiter.*—It has already been stated that Jupiter is attended by four satellites. These, with their *primary* planet, constitute a miniature system, analogous, in

the laws of its motions, to the great solar system in which the sun acts the part of primary, and the planets of satellites. The orbits of the satellites are ellipses of very moderate eccentricity, the primary occupying one focus. The eclipses of Jupiter's satellites, which happen very frequently, afford signals of considerable use for the determination of terrestrial longitudes. This method, indeed, until superseded by the greater exactness and facility now attainable by lunar observations, was the only one which could be relied on for great distances and long intervals. The following table, copied from Sir J. Herschel's Astronomy, exhibits a synoptical view of the distances and periods in this system, so far as they are at present known. The distances are expressed in equatorial radii of the primary. The epoch is January 1, 1801. The periods, &c., are expressed in mean solar days.

Sat.	Mean Distance.	Sidereal Revolution.	Inclination of Orbit to that of Jupiter.	Mass: that of Jupiter being 1000000000
1.	6·04853	$1^{d.}$ $18^{h.}$ $28^{m.}$	30° 5′ 30″	17328
2.	9·62347	3 13 14	Variable.	23235
3.	15·35024	7 3 43	Variable.	88497
4.	26·99835	16 16 32	2 58 48	42659

720. *Satellites of Herschel.*—Herschel is supposed to be attended by six satellites. Of these, two undoubtedly exist, and four have been suspected. "These two, however, offer remarkable, and indeed, quite unexpected and unexampled peculiarities. Contrary to the unbroken analogy of the whole planetary system,—whether of primaries or secondaries—the planes of their orbits *are nearly perpendicular to the ecliptic*, being inclined no less than 78° 58′ to that plane, and in these orbits their motions *are retrograde;* that is to say, their positions, when projected on the ecliptic, instead of advancing *from west to east* round the centre of their primary, as is the case with every other planet and satellite, move in the opposite direction. Their orbits are nearly or quite circular, and they do not appear to have any sensible, or, at least, any rapid motion of nodes, or to have undergone any material change of inclination, in the course, at least, of half a revolution of their primary round the sun.

Sat.	Mean Distance.	Sidereal Period.	Inclination to Ecliptic.
1.?	13·120	$5^{\mathrm{d.}}$ $21^{\mathrm{h.}}$ $25^{\mathrm{m.}}$ $0^{\mathrm{s.}}$	Their orbits are inclined about 78° 58′ to the ecliptic, and their motion is retrograde. The periods of the second and fourth require a trifling correction. The orbits appear to be nearly circles.
2.	17·022	8 16 56 6	
3.?	19·845	10 23 4 0	
4.	22·752	13 11 8 59	
5.?	45·507	38 1 48 0	
6.?	91·008	107 16 40 0	

Sir J. Herschel's Astronomy.

721. *Satellites of Saturn.*—Saturn is attended by seven satellites. Of these, the most distant is by far the largest, and is probably not much inferior in size to Mars. Its orbit is also materially inclined to the plane of the ring, with which those of all the rest nearly coincide. The next in order (proceeding inwards) is tolerably conspicuous; the next three are very minute, and require a tolerably powerful telescope to see them; while the two interior, which just skirt the edge of the ring, and move exactly in its plane, require the most powerful telescopes which have yet been constructed to view them. The following table is taken from the work of Sir John Herschel:—

Sat.	Mean Distance.	Sidereal Revolution.	Eccentricities and Inclinations.
1.	3·351	$0^{\mathrm{d.}}$ $22^{\mathrm{h.}}$ $38^{\mathrm{m.}}$	The orbits of the six interior satellites are nearly circular, and very nearly in the plane of the ring. That of the seventh is considerably inclined to the rest, and approaches nearer to coincidence with the ecliptic.
2.	4·300	1 8 53	
3.	5·284	1 21 18	
4.	6·819	2 17 45	
5.	9·524	4 12 25	
6.	22·081	15 22 41	
7.	64·359	79 7 55	

ECLIPSES.

722. "Every planet and satellite in the solar system is illuminated by the sun, and hence they cast shadows in the direction opposite to him, just as the shadow of a man reaches in a direction from the sun. A shadow is nothing more than the interception of the rays of light by an opaque body. The

earth always makes a shadow, which reaches to an immense distance into open space, in the direction opposite to the sun. When the earth, turning on its axis, carries us out of the sphere of the sun's light, we say it is *sunset*, and then we pass into the earth's shadow, and night comes on. When the earth turns half round from this point, and we again emerge out of the earth's shadow, we say, the *sun rises*, and then day begins.

723. "Now an eclipse of the moon is nothing more than her falling into the shadow of the earth. The moon, having no light of her own, is thus darkened, and we say she is *eclipsed.* The shadow of the moon also reaches to a great distance from her. We know that it reaches at least 240,000 miles, because it sometimes reaches the earth. An eclipse of the sun is occasioned whenever the earth falls into the shadow of the moon. Hence, in eclipses, whether of the sun or moon, the two planets and the sun must be nearly in a straight line with respect to each other. In eclipses of the moon, the earth is between the sun and moon, and in eclipses of the sun, the moon is between the earth and sun.

724. "If the moon went round the sun in the same plane with the earth, that is, were the moon's orbit on the plane of the ecliptic, there would happen an eclipse of the sun at every conjunction of the sun and moon, or at the time of every new moon. But at these conjunctions the moon does not come exactly between the earth and sun, because the orbit of the moon is inclined to the ecliptic at an angle of 5½ degrees. Did the planes of the orbits of the earth and moon coincide, there would be an eclipse of the moon at every full, for then the moon would pass exactly through the earth's shadow.

725. "One half of the moon's orbit being elevated 5½ degrees above the ecliptic, the other half is depressed as much below it, and thus the moon's orbit crosses that of the earth in two opposite points, called the moon's *nodes*. As the nodes of the moon are the points where she crosses the ecliptic, she must be half the time above, and the other half below these points. The node in which she crosses the plane of the ecliptic upward, or towards the north, is called her *ascending* node That in which she crosses the same plane downward, or towards the south, is called her *descending* node.

726. "The moon's orbit, like those of the other planets, is elliptical, so that she is sometimes nearer the earth than at

others. When she is at that part of her orbit which is at the greatest distance from the earth, she is said to be in her *apogee*, and when at her least distance from the earth, she is in her *perigee*.

727. "Eclipses can only happen at the time when the moon is at, or near, one of her *nodes*, for at no other time is she near the plane of the earth's orbit; and since the earth is always in this plane, the moon must be at, or near it, also, in order to bring the two planets and the sun in the same right line, without which no eclipse can happen.

728. "The reason why eclipses do not happen oftener, and at regular periods, is because a node of the moon is usually only twice, and never more than three times in the year, presented towards the sun. The average number of total eclipses of both luminaries, in a century, is about thirty, and the average number of total and partial, in a year, about four. There may be seven eclipses in a year, including those of both luminaries, and there may be only two. When there are only two, they are both of the sun. When the moon is within 16½ degrees of her node, at the time of her change, she is so near the ecliptic, that the sun may be more or less eclipsed, and when she is within 12 degrees of her node, at the time of her full, the moon will be more or less eclipsed.

729. "But the moon is more frequently within 16½ degrees of her node at the time of her change, than she is within 12 degrees at the time of her full, and consequently there will be a greater number of solar, than of lunar eclipses, in a course of years. Yet more lunar eclipses will be visible, at any one place on the earth, than solar, because the sun, being so much larger than the earth, or moon, the shadow of these bodies must terminate in a point, and this point of the moon's shadow never covers but a small portion of the earth's surface, while lunar eclipses are visible over a whole hemisphere, and as the earth turns on its axis, are therefore visible to more than half the earth. This will be obvious by Figs. 240 and 241, where it will be observed that an eclipse of the moon may be seen wherever the moon is visible, while an eclipse of the sun will be total only to those who live within the space covered by the moon's dark shadow.

730. "LUNAR ECLIPSES.—When the moon falls into the shadow of the earth, the rays of the sun are intercepted, or hid from her, and she then becomes eclipsed. When the earth's shadow covers only a part of her face, as seen by us,

she suffers only a *partial* eclipse, one part of her disk being obscured, while the other part reflects the sun's light. But when her whole surface is obscured by the earth's shadow, she then suffers a total eclipse, and of a duration proportionate to the distance she passes through the earth's shadow. Fig. 240 represents a total lunar eclipse; the moon being in the midst of the earth's shadow. Now it will be apparent that in the situation of the sun, earth, and moon, as represented in the figure, this eclipse will be visible from all parts of that hemisphere of the earth which is next the moon, and that the moon's disk will be equally obscured, from whatever point it is seen. When the moon passes through only a part of the earth's shadow, then she suffers only a partial eclipse, but this is also visible from the whole hemisphere next the moon. It will be remembered that lunar eclipses happen only at full moon, the sun and moon being in opposition, and the earth between them.

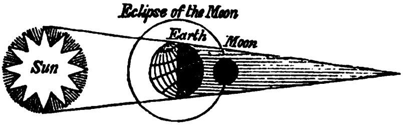

Fig. 240.

731. "SOLAR ECLIPSES.—When the moon passes between the earth and sun, there happens an eclipse of the sun, because then the moon's shadow falls upon the earth. A total eclipse of the sun happens often, but when it occurs, the total obscurity is confined to a small part of the earth; since the dark portion of the moon's shadow never exceeds 200 miles in diameter on the earth. But the moon's partial shadow, or *penumbra*, may cover a space on the earth of more than 4000 miles in diameter, within all which space the sun will be more or less eclipsed. When the penumbra first touches the earth, the eclipse begins at that place, and ends when the penumbra leaves it. But the eclipse will be

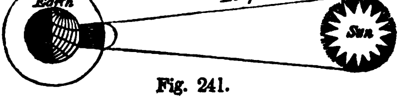

Fig. 241.

total only where the dark shadow of the moon touches the earth. Fig. 241 represents an eclipse of the sun, without regard to the penumbra, that it may be observed how small a part of the earth the dark shadow of the moon covers. To those who live within the limits of this shadow, the eclipse will be total, while to those who live in any direction around it, and within reach of the penumbra, it will be only partial.

732. "Solar eclipses are called *annular*, from *annulus*, a ring, when the moon passes across the centre of the sun, hiding all his light, with the exception of a ring on his outer edge, which the moon is too small to cover from the position in which it is seen. Fig. 242 represents a solar eclipse, with the penumbra D C, and the *umbra*, or dark shadow, as seen in the above figure. When the moon is at its greatest distance from the earth, its shadow M O, sometimes terminates, before it reaches the earth, and then an observer standing directly under the point O, will see the outer edge of the sun, forming a bright ring around the circumference of the moon, thus forming an *annular* eclipse.

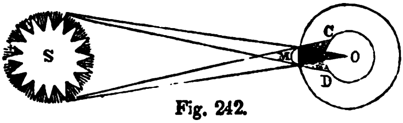

Fig. 242.

733. "The *penumbra* D C, is only a partial interception of the sun's rays, and in annular eclipses it is this partial shadow only which reaches the earth, while the umbra, or dark shadow, terminates in the air. Hence annular eclipses are never total in any part of the earth. The penumbra, as already stated, may cover more than 4000 miles of space, while the umbra never covers more than 200 miles in diameter; hence partial eclipses of the sun may be seen by a vast number of inhabitants, while comparatively few will witness the total eclipse.

734. "When there happens a total solar eclipse to us, we are eclipsed to the moon, and when the moon is eclipsed to us, an eclipse of the sun happens to the moon. To the moon, an eclipse of the earth can never be total, since her shadow covers only a small portion of the earth's surface. Such an eclipse, therefore, at the moon, appears only as a dark spot on the face of the earth; but when the moon is eclipsed to

us, the sun is partially eclipsed to the moon for several hours longer than the moon is eclipsed to us."

THE TIDES.

735. The ocean rises and falls alternately. Its depth is observed to be greatest at any given place at a certain time after the moon has passed the meridian of that place; it then decreases in depth to a certain degree, after which it again gradually rises. These phenomena recur after nearly the same intervals of time, and are called the *ebbing* and *flowing* of the ocean, or, more commonly, the *tides*. The interval of time between low water and the following high water is called *flood tide;* and that between high and low water, *ebb tide*. If the interval of time between two successive passages of the moon over the same semi-meridian be called a lunar day, there are generally, or on an average, two high tides in one lunar day.

736. "The cause of the tides is the attraction of the sun and moon, but chiefly of the moon, on the waters of the ocean. In virtue of the universal principle of gravitation, already explained, the moon, by her attraction, draws, or raises the water towards her; but, because the power of attraction diminishes as the squares of the distances increase, the waters, on the opposite side of the earth, are not so much attracted as they are on the side nearest the moon. This want of attraction, together with the greater centrifugal force of the earth on its opposite side, produced in consequence of its greater distance from the common centre of gravity, between the earth and moon, causes the waters to rise on the opposite side, at the same time that they are raised by direct attraction on the side nearest the moon.

737. "Thus the waters are constantly elevated on the sides of the earth opposite to each other above their common level, and consequently depressed at opposite points equally distant from these elevations. Let M, Fig. 243, be the moon, and E the earth covered with water. 1. As the moon passes round the earth, its solid and fluid parts are equally attracted

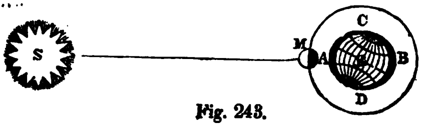

Fig. 243.

by her influence according to their densities; but while the solid parts are at liberty to move only as a whole, the water obeys the slightest impulse, and thus tends towards the moon where her attraction is the strongest. Consequently, the waters are perpetually elevated immediately under the moon. If, therefore, the earth stood still, the influence of the moon's attraction would raise the tides only as she passed round the earth. 2. But as the earth turns on her axis every 24 hours, and as the waters nearest the moon, as at A, are constantly elevated, they will, in the course of 24 hours, move round the whole earth, and consequently from this cause there will be high water at every place once in 24 hours. 3. As the elevation of the waters under the moon causes their depression at 90 degrees' distance on the opposite sides of the earth, D and C, the point C will come to the same place, by the earth's diurnal revolution, six hours after the point A, because C is one quarter of the circumference of the earth from the point A, and therefore there will be low water at any given place six hours after it was high water at that place. 4. But while it is high water under the moon, in consequence of her direct attraction, it is also high water on the opposite side of the earth, in consequence of her diminished attraction and the earth's centrifugal motion, and therefore it will be high water from this cause twelve hours after it was high water from the former cause, and six hours after it was low water from both causes.

738. "Thus when it is high water at A and B, it is low water at C and D, and as the earth revolves once in 24 hours, there will be an alternate ebbing and flowing of the tide, at every place, once in six hours. But while the earth turns on her axis, the moon advances in her orbit, and consequently any given point on the earth will not come under the moon on one day so soon as it did on the day before. For this reason, high or low water at any place occurs about fifty minutes later on one day than it did the day before.

739. "Thus far we have considered no other attractive influence except that of the moon, as affecting the waters of the ocean. But the sun, as already observed, has an effect upon the tides, though on account of his great distance, his influence is small when compared with that of the moon. When the sun and moon are in conjunction, as represented in Fig. 243, which takes place at her change, or when they are in opposition, which takes place at full moon, then their

forces are united, or act on the waters in the same direction, and consequently the tides are elevated higher than usual, and on this account are called *spring tides.*

740. "But when the moon is in her quadratures, or quarters, the attraction of the sun tends to counteract that of the moon, and although his attraction does not elevate the waters and produce tides, his influence diminishes that of the moon, and consequently the elevation of the waters is less when the sun and moon are so situated in respect to each other, than when they are in conjunction, or opposition. This effect is represented by Fig. 244, where the elevation of the tides at C and D is produced by the causes already explained; but their elevation is not so great as in Fig. 243, since the influence of the sun acting in the direction A B, tends to counteract the moon's attractive influence. These small tides are called *neap tides*, and happen only when the moon is in her quadratures.

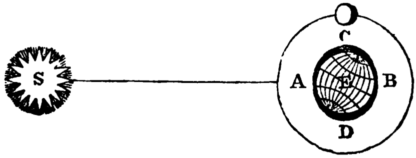

Fig. 244.

741. "The tides are not at their greatest heights at the time when the moon is at its meridian, but some time afterwards, because the water, having a motion forward, continues to advance by its own inertia, some time after the direct influence of the moon has ceased to affect it." This may be also observed with respect to the greatest heat and cold, which are not felt on the solstitial days, when the action of the sun is greatest and least.

742. The tides rise to different heights in different parts of the world; in the Bristol channel they rise above forty feet, and on the eastern coast of North America more than fifty feet; but their average height is considerably under twenty feet. In the Mediterranean sea, the tides are small, and in some places scarcely perceptible; this is occasioned by the inland character of that sea, and by the arrest given to the rise and fall of the tides by the straits of Gibraltar.

LATITUDE AND LONGITUDE.

743. The situation of places on the surface of the earth* is determined, as to north or south, by their *latitude*, and as to east and west, by their *longitude;* and these distances are reckoned by *degrees*, *minutes*, and *seconds*. Every circle, whatever may be its diameter, is divided into 360 degrees—a mode of division suggested by the supposed passage of the sun through the ecliptic, or great circle of the heavens, in 360 days, each day's progress being termed a *gradus*, step or degree. Each degree is subdivided into 60 minutes, or miles, and each minute into 60 seconds. These divisions are denoted by the signs °, ′, ″; thus 55°, 34′, 23″, signify 55 degrees, 34 minutes or miles, and 23 seconds. Further, N. stands for north, S. for south latitude; E. for east, W. for west longitude.

744. The mile of which we have here spoken, is the *geographical mile*, and must not be confounded with the *British statute mile*, or the common itinerary measure of this country, and of which 69⅛ are contained in a degree of latitude. The former is, however, always understood to be employed, unless the latter be specified.

745. "*Latitude* is the distance from the equator in a direct line, north or south, measured in degrees and minutes. The number of degrees is 90 north, and as many south, each line on which these degrees are reckoned running from the equator to the poles. Places on the north of the equator are in *north latitude*, and those on the south of the equator are in *south latitude*. The *parallels* of latitude are imaginary lines drawn parallel to the equator, either north or south, and hence every place situated on the same parallel is in the same latitude, because every such place must be at the same distance from the equator. The length of a degree of latitude is 60 geographical miles.

746. "*Longitude* is the distance measured in degrees and minutes, either east or west, from any given point on the equator, or on any parallel of latitude. Hence the lines, or

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* The surface of the earth comprises 148,187,500 square miles, of which about one-fourth part, or 39,956,500 square miles, is land, and the remaining three-fourths, or 108,231,000 square miles, are water. The estimated number of square miles contained in each quarter of the globe, is as follows:—

	Square Miles.		Square Miles.
Europe,	2,635,700	*Africa*,	8,902,000
Asia,	15 526,300	*America*,	12,892,000

meridians of longitude, cross those of latitude at right angles. The degrees of longitude are 180 in number, its lines extending half a circle to the east, and half a circle to the west, from any given meridian, so as to include the whole circumference of the earth. A degree of longitude, at the equator, is of the same length as a degree of latitude, but as the poles are approached, the degrees of longitude diminish in length, because the earth grows smaller in circumference from the equator towards the poles; hence the lines surrounding it become less and less

747. "This will be made obvious by Fig. 245. Let this figure represent the earth, N being the north pole, S the south pole, and E W the equator. The lines 10, 20, 30, and so on, are the parallels of latitude, and the lines N A S, N B S, &c., are meridian lines, or those of longitude. The latitude of any place on the globe, is the number of degrees between that place and the equator, measured on a meridian line; thus, X is in latitude 40 degrees, because the X G part of the meridian contains 40 degrees. The longitude of a place is the number of degrees it is situated east or west from any meridian line; thus, V is 20 degrees west longitude from X, and X is 20 degrees east longitude from V.

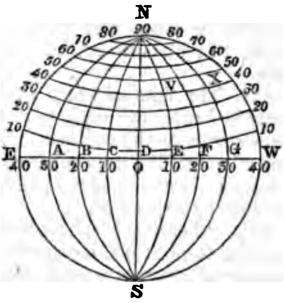


Fig. 245.

748. "As the equator divides the earth into two equal parts, or hemispheres, there seems to be a natural reason why the degrees of latitude should be reckoned from this great circle. But from east to west there is no natural division of the earth, each meridian line being a great circle, dividing the earth into two hemispheres, and hence there is no natural reason why longitude should be reckoned from one meridian any more than another. It has, therefore, been customary for writers and mariners to reckon longitude from the capital of their own country, as the English from London, the French from Paris, and the Americans from Washington. But this mode, it is apparent, must occasion much confusion, since each writer of a different nation would be obliged to correct

the longitude of all other countries, to make it agree with his own. More recently, therefore, the writers of Europe and America have selected the royal observatory, at Greenwich, near London, as the first meridian, and on most maps and charts lately published, longitude is reckoned from that place.

749. "*How latitude is found.*—The latitude of any place is determined by taking the altitude of the sun at mid-day, and then subtracting this from 90 degrees, making proper allowances for the sun's place in the heavens. The reason of this will be understood, when it is considered that the whole number of degrees from the zenith to the horizon is 90, and therefore if we ascertain the sun's distance from the horizon, that is, his altitude, by allowing for the sun's declination north or south of the equator, and subtracting this from the whole number, the latitude of the place will be found. Thus, suppose that on the 20th of March, when the sun is at the equator, his altitude from any place north of the equator should be found to be 48 degrees above the horizon; this, subtracted from 90, the whole number of the degrees of latitude, leaves 42, which will be the latitude of the place where the observation was made.

750. "If the sun, at the time of observation, has a declination north or south of the equator, this declination must be added to, or subtracted from, the meridian altitude, as the case may be. For instance, another observation being taken at the place where the latitude was found to be 42, when the sun had a declination of 8 degrees north, then his altitude would be 8 degrees greater than before, and therefore 56, instead of 48. Now, subtracting this 8, the sun's declination, from 56, and the remainder from 90, the latitude of the place will be found 42, as before. If the sun's declination be south of the equator, and the latitude of the place north, his declination must be added to the meridian altitude, instead of being subtracted from it. The same result may be obtained by taking the meridian altitude of any of the fixed stars, whose declinations are known, instead of the sun's, and proceeding as above directed.

751. "*How longitude is found.*—There is more difficulty in ascertaining the degrees of longitude, than those of latitude, because, as above stated, there is no fixed point, like that of the equator, from which its degrees are reckoned. The degrees of longitude are therefore estimated from Greenwich, and are ascertained by the following methods:—

752. "When the sun comes to the meridian of any place, it is noon, or 12 o'clock, at that place, and therefore, since the equator is divided into 360 equal parts, or degrees, and since the earth turns on its axis once in 24 hours, 15 degrees of the equator will correspond with one hour of time, for 360 degrees being divided by 24 hours, will give 15. The earth, therefore, moves in her daily revolution, at the rate of 15 degrees for every hour of time. Now, as the apparent course of the sun is from east to west, it is obvious that he will come to any meridian lying east of a given place, sooner than to one lying west of that place, and therefore it will be 12 o'clock to the east of any place, sooner than at that place, or to the west of it. When, therefore, it is noon at any one place, it will be 1 o'clock at all places 15 degrees to the east of it, because the sun was at the meridian of such places an hour before; and so, on the contrary, it will be eleven o'clock, fifteen degrees west of the same place, because the sun has still an hour to travel before he reach the meridian of that place. It makes no difference, then, where the observer is placed, since, if it is 12 o'clock where he is, it will be 1 o'clock 15 degrees to the east of him, and 11 o'clock 15 degrees to the west of him, and so in this proportion, let the time be more or less. Now, if any celestial phenomenon should happen, such as an eclipse of the moon, or of Jupiter's satellites, the difference of longitude between two places where it is observed, may be determined by the difference of the times at which it appeared to take place. Thus, if the moon enters the earth's shadow at 6 o'clock in the evening, as seen at Philadelphia, and at half past 6 o'clock at another place, then this place is half an hour, or 7½ degrees, to the east of Philadelphia, because 7½ degrees of longitude are equal to half an hour of time. To apply these observations practically, it is only necessary that it should be known exactly at what time the eclipse takes place at a given point on the earth.

753. "Longitude is also ascertained by means of a chronometer, or true time-piece, adjusted to any given meridian; for if the difference between two clocks, situated east and west of each other, and going exactly at the same rate, can be known at the same time, then the distance between the two meridians, where the clocks are placed will be known, and the difference of longitude may be found.

754. "Suppose two chronometers, which are known to go at exactly the same rate, are made to indicate 12 o'clock by

the meridian line of Greenwich, and the one be taken to sea, while the other remains at Greenwich. Then suppose the captain, who takes his chronometer to sea, has occasion to know his longitude. In the first place, he ascertains, by an observation of the sun, when it is 12 o'clock at the place where he is, and then by his time-piece, when it is 12 o'clock at Greenwich, and by allowing 15 degrees for every hour of the difference in time, he will know his precise longitude in any part of the world. For example, suppose the captain sails with his chronometer for America, and after being several weeks at sea, finds by observation that it is 12 o'clock by the sun, and at the same time finds by his chronometer that it is 4 o'clock at Greenwich. Then because it is noon at his place of observation after it is noon at Greenwich, he knows that his longitude is west from Greenwich, and by allowing 15 degrees for every hour of the difference, his longitude is ascertained. Thus, 15 degrees, multiplied by 4 hours, give 60 degrees of west longitude from Greenwich. If it is noon at the place of observation, before it is noon at Greenwich, then the captain knows that his longitude is east, and his true place is found in the same manner."

THE FIXED STARS.

755. Besides the bodies which have been described, an innumerable multitude of luminaries, which have not been observed to change their places with respect to each other, may be seen in the heavens. These are termed *fixed stars*, not because it is absolutely denied that they are in a state of motion, but because their motion, if any, is exceedingly slow, and inappreciable by us, in consequence of the stupendous distances at which they are placed from our system. The fixed stars may be distinguished from the planets by their scintillations or twinkling.

756. *Classification of fixed stars.*—The fixed stars have been classified, according to their comparative brightness, into stars of the first, second, and so on to the sixth or seventh *magnitude*. 1. By the use of powerful instruments, this mode of distribution has been extended to stars of the sixteenth magnitude, and would probably admit of unlimited application, if our instruments were susceptible of adequate improvement. About 15 or 20 stars are usually referred by astronomers to the first magnitude; from 50 to 60 to the second; about 200 to the third; and so on, according to

their decreasing brightness, including a catalogue of nearly 20,000 stars, which have been reckoned down to the seventh magnitude. It was observed by Kepler that the surface of a sphere presents only thirteen points equally distant from each other, and from the centre; hence, supposing that the nearest fixed stars are as distant from each other as they are from the sun, he concludes that there are only thirteen stars of the first magnitude. At twice the distance from the sun, there may be four times as many, or fifty-two stars of the second magnitude; and so on. This ingenious suggestion indicates, with tolerable accuracy, the number of stars usually referred to first, second, and third magnitude.

757. *Distances of the fixed stars.*—"The nearest fixed stars to our system, from the most accurate astronomical calculations, cannot be nearer than 20,000,000,000,000, or 20 trillions of miles from the earth, a distance so immense, that light cannot pass through it in less than three years. Hence, were these stars annihilated at the present time, their light would continue to flow towards us, and they would appear to be in the same situation to us, three years hence, that they do now. Our sun, seen from the distance of the nearest fixed stars, would appear no larger than a star of the first magnitude does to us. These stars appear no larger to us, when the earth is in that part of her orbit nearest to them, than they do when she is in the opposite part of her orbit; and as our distance from the sun is 95,000,000 of miles, we must be twice this distance, or the whole diameter of the earth's orbit, nearer a given fixed star at one period of the year than at another. The difference, therefore, of 190,000,000 of miles, bears so small a proportion to the whole distance between us and the fixed stars, as to make no appreciable difference in their sizes, even when assisted by the most powerful telescopes.

758. "The amazing distances of the fixed stars may also be inferred from the return of comets to our system, after an absence of several hundred years. The velocity with which some of these bodies move, when nearest the sun, has been computed at nearly a million of miles in an hour, and although their velocities must be perpetually retarded, as they recede from the sun, still, in 250 years of time, they must move through a space which to us would be infinite. The periodical return of one comet is known to be upwards of 500 years, making more than 250 years in performing its

journey to the most remote part of its orbit, and as many in returning back to our system; and that it must still always be nearer our system than the fixed stars, is proved by its return; for by the laws of gravitation, did it approach nearer another system it would never again return to ours.

759. "From such proofs of the vast distances of the fixed stars, there can be no doubt that they shine with their own light, like our sun, and hence the conclusion that they are suns to other worlds, which move around them, as the planets do around our sun. Their distances will, however, prevent our ever knowing, except by conjecture, whether this is the case or not, since, were they millions of times nearer us than they are, we should not be able to discover the reflected light of their planets."

760. *Milky way.*—"There are not wanting," observes Sir J. Herschel, "*natural* districts in the heavens, which offer great peculiarities of character, and strike every observer: such is the *milky way*, that great luminous band, which stretches, every evening, all across the sky, from horizon to horizon, and which, when traced with diligence, and mapped down, is found to form a zone completely encircling *the whole sphere*, almost in a great circle, which is neither an *hour* circle, nor coincident with any other of our astronomical *grammata*. It is divided in one part of its course, sending off a kind of branch, which unites again with the main body, after remaining distinct for about 150 degrees. This remarkable belt has maintained, from the earliest ages, the same relative situation among the stars; and, when examined through powerful telescopes, is found (wonderful to relate) *to consist entirely of stars scattered by millions*, like glittering dust, on the black ground of the general heavens.

761. *Periodical stars.*—"Among the stars are several which, though no way distinguishable from others by any apparent change of place, nor by any difference of appearance in telescopes, yet undergo a regular periodical increase and diminution of lustre, involving, in one or two cases, a complete extinction and revival. These are called *periodical stars*. One of the most remarkable is the star *Omicron*, in the constellation *Cetus*, first noticed by Fabricius in 1596. It appears about twelve times in eleven years, or more exactly, in a period of 334 days; remains at its greatest brightness about a fortnight, being then, on some occasions, equal to a large star of the second magnitude; decreases during about

three months, till it becomes completely invisible, in which state it remains during about five months, when it again becomes visible, and continues increasing during the remaining three months of its period."—*Herschel's Astronomy*.

762. *Temporary stars.*—Sir J. Herschel describes other phenomena of stellar variation, under the term of *temporary stars*, which have appeared, from time to time, in different parts of the heavens, blazing forth with extraordinary lustre; and, after remaining a while apparently immoveable, have died away and left no trace. The appearance of a star of this kind, in 1572, was so sudden, that Tycho Brahe, returning one evening (Nov. 11) from his laboratory to his dwelling-house, was surprised to find a group of country people gazing at a star, which he was sure did not exist half an hour before. It was then as bright as Sirius, and continued to increase till it surpassed Jupiter when brightest, and was visible at midday. It began to diminish in December of the same year, and in March, 1574, had entirely disappeared. So, also, on the 10th of October, 1604, a star of this kind, and not less brilliant, burst forth in the constellation of Serpentarius, and continued visible till October 1605.

COMETS.

763. "Besides the planets which move round the sun in regular order, and in nearly circular orbits, there belongs to the solar system an unknown number of bodies called *comets*, (or *hairy stars*,) which move round the sun in orbits exceedingly eccentric, or elliptical, and whose appearance among our heavenly bodies is only occasional. Comets, to the naked eye, have no visible disk, but shine with a faint, glimmering light, and are accompanied by a *train* or *tail*, turned from the sun, and which is sometimes of immense length. They appear in every region of the heavens, and move in every possible direction.

764. "It had been supposed that comets moved in straight lines, coming from the regions of infinite, or unknown space, and merely passing by our system, on their way to regions equally unknown and infinite, and from which they never returned. Sir Isaac Newton was the first to demonstrate that the comets pass round the sun, like the planets, but that their orbits are exceedingly elliptical, and extend out to a vast distance beyond the solar system.

765. "The number of comets is unknown, though some

astronomers suppose that there are nearly 500 belonging to our system. Ferguson, who wrote in about 1760, supposed that there were fewer than 30 comets which made us occasional visits; but since that period the elements of the orbits of nearly 100 of these bodies have been computed. Of these, however, there are only three whose periods of return among us are known with any degree of certainty. The first of these has a period of 75 years; the second a period of 129 years; and the third a period of 575 years. The third appeared in 1682, and therefore cannot be expected again until the year 2257. This comet, Fig. 246, in 1682, excited the most intense interest among the astronomers of Europe, on account of its great apparent size and near approach to our system. In the most remote part of its orbit, its distance from the sun was estimated at about eleven thousand two hundred millions of miles. At its nearest approach to the sun, which was only about 50,000 miles, its velocity, according to Sir Isaac Newton, was 880,000 miles in an hour; and supposing it to have retained the sun's heat, like other solid bodies, its temperature must have been about 2000 times that of red hot iron. The tail of this comet was at least 100 millions of miles long.

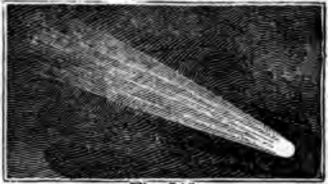


Fig. 246.

766. "In the Edinburgh Encyclopedia, article *Astronomy*, there is the most complete table of comets yet published. This table contains the elements of 97 comets, calculated by different astronomers, down to the year 1808. From this table it appears that 24 comets have passed between the sun and the orbit of Mercury; 33 between the orbits of Venus and the Earth; 15 between the orbits of the Earth and Mars; 3 between the orbits of Mars and Ceres; and 1 between the orbits of Ceres and Jupiter. It also appears by this table that 49 comets have moved round the sun from west to east, and 48 from east to west.

767. "Of the nature of these wandering planets very little is known. When examined by a telescope, they appear like a mass of vapours surrounding a dark nucleus. When the comet is at its perihelion, or nearest the sun, its colour seems to be heightened by the intense light or heat of that luminary,

and it then often shines with more brilliancy than the planets. At this time the *tail* or *train*, which is always directly opposite to the sun, appears at its greatest length, but is commonly so transparent as to permit the fixed stars to be seen through it. A variety of opinions have been advanced by astronomers concerning the nature and causes of these trains. Newton supposed that they were thin vapour, made to ascend by the sun's heat, as the smoke of a fire ascends from the earth; while Kepler maintained that it was the atmosphere of the comet driven behind it by the impulse of the sun's rays. Others suppose that this appearance arises from streams of electric matter passing away from the comet," &c.

768. The comet, above noticed (§ 765), has been named from Edmund Halley, who considered it the same as that which had appeared in 1531 and 1607. He, accordingly, *predicted* its reappearance about the year 1759, and on the 12th of March in that year it actually re-appeared. This is the first comet whose *periodicity* was foretold, and the truth of the prediction verified. Its next return to the perihelion was calculated by M. Damoiseau, and fixed for the year 1835. The intervals of its returns are therefore 75 or 76 years. The comet, named from Prof. Encke, of Berlin, completes its orbit in about 3⅓ years. Its return was calculated in 1819, and the result of the calculation verified by its several reappearances in 1822, 1825, 1828, &c. The comet of Biela is identical with that which appeared in 1789, 1795, &c. It describes its elliptic orbit about the sun in 6¾ years, and was seen in 1832 and 1838. The periods of this comet are continually diminishing; in other words, its mean distance from the sun, or the major axis of the ellipse, are dwindling by slow but regular degrees.

769. The probability of a comet coming in collision with the earth, or with any other planet, may be reduced to a very slight amount, if we compare with the small volume of the earth or any other planet, and that of comets, the immensity of the space in which these bodies move. M. Arago observes that the doctrine of chances affords us the means of estimating numerically the probability of such a collision, and shows that there is but one such chance in 281 millions; that is to say, that, on the appearance of a new comet, the odds are 281 millions to one that it will *not* strike against one globe.

QUESTIONS ON CHAP. IX.

539. WHAT does the term astronomy denote? What is its object? How is the subject divided? What does descriptive astronomy teach? What is the object of physical astronomy? What is practical astronomy? How are the heavenly bodies divided? 540. Which are the principal systems of astronomy? Explain the systems of Ptolemy, of Copernicus, and of Tycho Brahe.

541. Of what does the solar system consist? What are the bodies called which revolve round the sun as a centre? What is the difference between a primary and a secondary planet? Which of the planets are attended by satellites, and how many has each? 542. How long a time does each planet occupy in revolving round the sun?—544. What is a year?—545. In what direction do the planets move round the sun? What is the orbit of a planet?—546. What revolutions have the planets besides their yearly revolutions? Have all the planets diurnal revolutions? How is it know that the planets have daily revolutions? What is the axis of a planet? What is the pole of a planet?—547. Which are the superior, and which the inferior planets? How is it proved that the inferior planets are within the earth's orbit, and the superior ones without it?—548. Explain Fig. 213, and show why the inferior planets never can be in opposition to tho sun.—549. What are the shapes of the planetary orbits? What is meant by perihelion? What is meant by aphelion?

550. What is the plane of an orbit? Explain what is meant by the ecliptic. Why is the ecliptic called the sun's apparent path? 551. What is the zodiac? How does the ecliptic divide the zodiac? How far does the zodiac extend on each side of the ecliptic?—552. Explain Fig. 215, and show why the sun seems to pass through the ecliptic, when the earth only revolves around the sun.—553. What is a constellation or sign? How is the sun's apparent place in the heavens found?—554. Into how many parts are the signs of the zodiac divided, and what are these parts called?—555. Is there any resemblance between the places of the stars and the figures of the animals after which they are called? Explain why this is a convenient method of finding any particular star in a sign?—556. What are the names of the twelve signs?—557. Explain why the sun will be in the beginning of Aries, when the earth is at A, Fig. 216.

558. What is meant by density? In what proportion do bodies attract each other?—559. How are the densities of the planets ascertained? What is the density of the sun, of Mercury, and of the earth? In what proportions do the densities of the planets appear to diminish?—560. What is a sphere? Why is the spherical form of the heavenly bodies imperceptible? What is a hemisphere?

561. Where is the place of the sun in the solar system?—562. What is the distance of the sun from the earth? What is the sun's diameter?—563. What is the apparent motion of the sun? How is this apparent motion explained? How is it proved that the sun revolves on his own axis? How often does the sun revolve?—564. When were spots of the sun first observed? What has been the difference in the number of spots observed? What was the size of the spot seen by Dr Herschel?—565. What has been advanced concerning the nature of these spots? Have they been accounted for satisfactorily?—566. What is said concerning the sun's being a habitable globe?

567. What is the diameter of Mercury, and what are his periods of annual and diurnal revolution?—568. How great is the sun's heat at Mercury?—569. At what times is Mercury to be seen?—570. What is a transit of Mercury?—571. Where is the orbit of Venus in respect to that of the earth? What is the time of Venus's revolution round the sun? How often does she turn on her axis?—572. What is said of the height of the mountains in Venus? On what account are the transits of Venus observed with great care?—573. When is Venus the morning, and when the evening star? How long is Venus the morning, and how long the evening star?—574. How long does it take the earth to revolve round the sun? What is meant by the earth's annual revolution, and what by her diurnal revolution?

575. Why are the phenomena of the moon better explained than those of the other planets?—576. In what time is a revolution of the moon about the earth performed? What is the distance of the moon from the earth?—577. What is the diameter of Mars? How much longer is a year at Mars than our year? What is his rate of motion in his orbit?—578. What is his appearance through the telescope? How is it proved that Mars has an atmosphere of great density? How great is the sun's heat at Mars?—579. Why does Mars sometimes appear to us larger than at others?

581. Which are the new planets, or asteroids?—582. When was Vesta discovered? What is the period of Vesta's annual revolution?—583. When was Juno discovered? What is her distance from the sun? What is the period of her revolution, and what her diameter?—584, 585. What is said of Pallas and Ceres?

586. What is the diameter of Jupiter? What is his distance from the sun? What is the period of Jupiter's diurnal revolution?—587. What are the sun's heat and light at Jupiter, when compared with that of the earth?—588. For what is Jupiter particularly distinguished? Is the appearance of Jupiter's belts always the same, or do they change?—589. What is said of the cause of Jupiter's belted appearance?—590. How many moons has Jupiter, and what are the periods of their revolutions?—591. What occasions the eclipses of Jupiter's moons? Of what

use are these eclipses to astronomers? How is the velocity of light ascertained by the eclipses of Jupiter's satellites?

592. What is the time of Saturn's periodic revolution round the sun? What is his distance from the sun? What his diameter? What is the period of his diurnal revolution? How many days make a year at Saturn? How many moons has Saturn?—593. How is Saturn particularly distinguished from all the other planets? What distance is there between the body of Saturn and his inner ring? What distance is there between his inner and outer ring? What is the circumference of the outer ring?—595. How long is one of Saturn's sides alternately in the light and dark?—596. In what position is Saturn represented in Fig. 220?

597. What circumstance led to the discovery of Herschel? In what year, and by whom, was Herschel discovered? What is the distance of Herschel from the sun?—598. In what period is his revolution round the sun performed? What is the diameter of Herschel? What is the quantity of light and heat at Herschel, when compared with those of the earth?—599. How many satellites has Herschel?

602. Is the position of a heavenly body the same when observed at different points on the earth's surface? Do the fixed stars differ from the planets in this respect?—603. What is the general, and what the astronomical meaning of the term parallax? What is the difference between diurnal and annual parallax?—604. Explain Fig. 223. What is the greatest parallax of the nearest planet?—605. What is the parallax of the great orb?

607. Suppose a body to be acted on by two forces perpendicular to each other, in what direction will it move? Why does the ball, Fig. 224, move in a straight line?—608. Why does the earth, Fig. 225, move in a curved line? Explain Fig. 225, and show how the two forces act to produce a circular line of motion?—610. What is the projectile force of the earth called? What is the attractive force of the sun, which draws the earth towards him, called?—612. Explain Fig. 226, and show the reason why the velocity is increased from C to D, and why it is not retarded from D to G.—613. What is meant by a planet's passing through equal spaces in equal times?—615. How is it shown, that if the motion of a revolving body is increased, its projectile force is also increased? By what force is the earth's velocity increased as it approaches the sun? When the earth is nearest the sun, why does it not fall to him?—616. When the earth's centrifugal force is greatest, what prevents its flying to the sun?

617. State the three laws of Kepler. What conclusions did Newton draw from these laws?—618. Illustrate the first law of Kepler.—619. What principle is involved in the second law of Kepler? What is the cause of curvature of motion?—620. Can you illustrate the law of elliptic motion?—621. What important conclusion is deduced from the third law of Kepler?

623. What are the most obvious and convincing proofs that the earth revolves on its axis?—624. Were the earth's orbit a solid mass, could it be seen by us at the distance of the fixed stars? Suppose the earth stood still, how fast must the sun move to go round it in 24 hours? At what rate must the fixed stars move to go round the earth in 24 hours? —625. If the heavens appear to revolve every 10 hours at Jupiter, and every 24 hours at the earth, how can this difference be accounted for if they revolve at all? Is there any more reason to believe that the sun revolves round the earth than round any of the other planets? How can all the phenomena of the heavens be accounted for, if they do not revolve?

627. What is the axis of the earth? What are the poles of the earth? What is the equator? Where are the northern and southern hemispheres? What are the polar circles? Which is the arctic, and which the antarctic circle? Where is the tropic of Cancer and where the tropic of Capricorn? What is the Ecliptic?—628. What is meant by parallels? Explain the etymology of the word equator. What are the equinoctial points?—629. What are the tropics? To what distance do they extend north and south of the equator?—630. What are the solstices? What does the term signify?—631. What are the polar circles?—632. What are the meridian lines?—633. On what part of the earth is the torrid zone? How are the north and south temperate zones bounded? Where are the frigid zones? Which are the great and which the lesser circles of the earth?

634. What is the difference between the sensible and the rational horizon?—635. What is the axis of the ecliptic? What are the poles of the ecliptic?—636. How many degrees is the axis of the earth inclined to that of the ecliptic? What is said concerning the relative positions of the earth's axis and the plane of the ecliptic?—637. Are the orbits of the other planets parallel to the earth's orbit, or inclined to it?—638. What is meant by the earth's axis being parallel to itself?—640. How does it appear by Fig. 229 that the axis of the earth is parallel to itself in all parts of its orbit? How are the annual and diurnal revolutions of the earth illustrated by Fig. 229.—641. Explain by Fig. 230 why the days and nights would every where be equal, were the axis of the earth perpendicular to the plane of its orbit?—642. What is the cause of the unequal lengths of the days and nights in different parts of the world?

643. What are the causes which produce the seasons of the year?—644. In what position is the equator with respect to the ecliptic?—645. At what times in the year do the line of the ecliptic and that of the equinox intersect each other? What are these points of intersection called? Which is the autumnal and which the vernal equinox? At what time does the sun rise and set when he is in the equinoxes?—646. When the sun enters the summer solstice, what is said of the length of the days and nights? When does the sun enter the winter solstice, and

what is the proportion between the length of the days and nights?—648. At what season of the year is the whole arctic circle illuminated? At what season is the whole antarctic circle in the dark? While the people near the north pole enjoy perpetual day, what is the situation of those near the south pole? At what season will the days be longer than the nights everywhere between the equator and the arctic circle? At what season will the nights be longer than the days in the southern hemisphere?—649. When will the days and nights be equal in all parts of the earth?

650. At what season of the year is the whole arctic circle involved in darkness?—651. When are the days and nights equal all over the world? When is the sun in the vernal equinox?—653. What is the cause of the apparent motion of the sun from east to west? What is the apparent path of the sun, but the real path of the earth?—654. Had the earth's axis no inclination, why would the days and nights always be equal? How many degrees does the sun's light reach, north and south of him, on the earth?—655. During our winter, is the north pole turned to or from the sun? At the poles, how many days and nights are there in the year? When it is winter in the northern hemisphere, what is the season in the southern hemisphere?—656. What are the seasons at the equator?—657. At what rate does the earth move around the sun? How fast does it move around its axis at the equator?—658. How is the velocity of the earth ascertained?—659. Why are we insensible of the earth's motion?

661. At what season of the year is the sun at the greatest, and at what season the least distance from the earth? How is it ascertained that the earth moves in an elliptical orbit, by the appearance of the sun? When does the sun appear under the greatest apparent diameter, and when under the least? How much farther is the sun from us in July than in January? What effect does this difference produce on the earth? —662. How are the heat of summer and the cold of winter accounted for? Why do the perpendicular rays of summer produce greater effects than the oblique rays of winter? How is this illustrated by the convex and concave lenses?—663. How is the actual difference of the summer and winter rays shown?—664. Why is not the hottest season of the year at the period when the days are longest and the sun most vertical?

665. What is the general figure of the earth? How much less is the diameter of the earth at the poles than at the equator?—666. How is the convexity of the earth proved by the approach of a ship at sea? Explain Fig. 234. What other proofs of the globular shape of the earth are mentioned?—667. What proof is derived from the offing observed at sea?—668. What additional appearance is presented from lofty eminences on the earth's surface?—669—671. What further proofs are there of the globular form of the earth?—672. How is it shown by the vibrations of the pendulum that the earth is flattened at the poles?—673. In

what proportion is the polar less than the equatorial diameter? What is the earth called in reference to this figure?—674. How is it supposed that it came to have this form? How is the form of the earth illustrated by experiment? Explain the reason why a plastic ball will swell at the equator, when made to revolve.—675. What two causes render the weights of bodies less at the equator than at the poles?—676. What would be the consequence on the weights of bodies at the equator, did the earth turn over once in 84 minutes and 43 seconds?

677. The stars appear to move round the earth in less time than the sun; what does the difference amount to in a year? What is the year, measured by a star, called? What is that measured by the sun called?—678. How is the difference in time between the solar and sidereal year accounted for? The earth's orbit is but a point, in reference to a star; how is this illustrated?—679. Had the earth only a diurnal revolution, would the sidereal and solar time agree? Show by Fig. 236 how sidereal differs from solar time. Why does not the earth turn the same meridian to the sun at the same time every day?—680. How many times does the earth turn on her axis in a year? Why does she turn more times than there are days in the year?

681. Why are the solar days sometimes greater, and sometimes less, than 24 hours?—What is the difference between the time of a sun dial and a clock called? What are the causes of the difference between the sun and clock?—682. In explaining equation of time, what motion is considered as belonging to the sun, and what motion to the earth?—683. What is equal or mean time? What is apparent time?—684. Under what suppositions would the days be of equal length?

685. In Fig. 237, which is the celestial equator, and which the ecliptic? Through which of these circles does the false, and through which does the true sun pass? When the real sun arrives at A, and the false one at 1, are they both on the same meridian? Which is then the more westward?—686. When the two suns are at 1 and A, why will any meridian come first under the real sun? Were the true sun in place of the false one, why would the sun and clock agree? While the suns are passing from A to C, and from 1 to 3, will the sun be faster or slower than the clock?—687. When the two suns are at C and 3, why will the sun and clock agree? While the real sun is passing from B to C, which is faster, the clock or sun?—688. What does the place of the false sun represent in Fig. 237?—689, 690. The inclination of the earth's axis would make the sun and clock agree in March, and the other months above named; why then do they not actually agree at those times?—691. Were the earth's orbit a perfect circle, on what days would the sun and clock agree? How does the form of the earth's orbit interfere with the agreement of the sun and clock on those days?—692. At what times would the form of the earth's orbit bring the sun and clock to agree?—693. The inclination of the earth's axis would make the sun and clock

agree four times in the year, and the form of the earth's orbit would make them agree twice in the year; now show the reason why they do not agree from these causes on the above-mentioned days, and why they do agree on other days? On what days do the sun and clock agree?

694. What is a tropical year? What is a sidereal year?—695. What is the difference in the time which it takes the sun to complete his revolution in respect to a star, and in respect to the equinox? Explain what is meant by the precession of the equinoxes.—696. How many seconds of a degree does the equinox recede every year, when the sun's place is compared with a star?—697. How does Fig. 238 illustrate the precession of the equinoxes?—698. Explain Fig. 238, and show from what points the equinoxes fall back from year to year.—699. How many minutes in time is the precession of the equinoxes per year?—700. What effect does this precession produce on the fixed stars? How many years is a star in going forward one degree, in respect to the equinoxes? In how many years will the stars appear to have passed half around the heavens? In what period will the earth appear to have gone backwards one whole revolution?—701. In what respect is the precession of the equinoxes an important subject? What is the cause of the precession of the equinoxes?

702. What is the size of the moon as compared with that of the earth? What is its mean distance from the earth? What is the distance of the moon from the earth, as compared with the diameter of the sun's body? —703. How long is the moon in completing her revolution round the earth? What is the period from new moon to new moon again?—704. What are these two periods called? Why are not the periodical and synodical months equal?—705. How are these two revolutions of the moon illustrated by the two hands of a watch? Mention the time of several conjunctions between the two hands of a watch?—706. Why do not the moon's changes take place at the periods of her revolution around the earth?—707. How much longer does it take the moon to come again in conjunction with the sun, than it does to perform her periodical revolution?—708. How is it proved that the moon makes but one revolution on her axis as she passes around the earth? One half of the moon is never in the dark; explain why this is so. How long are the days and the nights in the other half?

709. How is it shown that the moon shines only by reflected light?—710. When is the moon said to be in conjunction with the sun, and when in opposition to the sun?—711. What are the phases of the moon? Describe Fig. 239, and show how the moon passes from change to full, and from full to change?—712. What is said concerning the phases of the earth, as seen from the moon? When is the earth in her change to the people of the moon?—713. Why do those who live on one side of the moon never see the earth?—714. How is it known that the earth shines upon the moon, as the moon does upon us?—715. What is said concerning the

moon's atmosphere?—716. How high are some of the mountains, and how deep the caverns of the moon?—717. What is said concerning the volcanoes of the moon? What is supposed concerning the lakes and seas of the moon? On what ground is it supposed that there is no water in the moon?—718. Explain the phenomena of the harvest moon and the hunters' moon.

719. What kind of orbit is described by the satellites of Jupiter? To what purpose has the observation of their eclipses been subservient?—720. What two peculiarities have been noticed in the satellites of Herschel? What is the form of their orbits?—721. With what degrees of distinctness may the satellites of Saturn be seen? What is the form of their orbits?

722. What is a shadow? When do we say it is sunset, and when do we say it is sunrise?—723. What occasions an eclipse of the moon? What causes eclipses of the sun? In eclipses of the moon, what planet is between the sun and moon? In eclipses of the sun, what planet is between the sun and earth?—724. Why is there not an eclipse of the sun at every conjunction of the sun and moon? How many degrees is the moon's orbit inclined to that of the earth?—725. What are the nodes of the moon? What is meant by the ascending and descending nodes of the moon?—726. What is the moon's apogee, and what her perigee?—727. Why must the moon be at or near one of her nodes, to occasion an eclipse?—728. Why do not eclipses happen often, and at regular periods? What is the greatest, and what the least number of eclipses that can happen in a year?—729. Why will there be more solar than lunar eclipses in the course of years? Why will more lunar than solar eclipses be visible at any one place?

730. Why is the same eclipse total at one place and only partial at another?—731. Why is a total eclipse of the sun confined to so small a part of the earth? What is meant by penumbra? What will be the difference in the aspect of the eclipse, whether the observer stand within the dark shadow, or only within the penumbra?—732. What is meant by annular eclipses?—733. Are annular eclipses ever total in any part of the earth? In annular eclipses, what part of the moon's shadow reaches the earth?—735. What is said concerning the eclipses of the earth, as seen from the moon?

735. What are the tides? What are flood tide and ebb tide?—736. What is the cause of the tides? What causes the tide to rise on the side of the earth opposite to the moon?—737. If the earth stood still, the tides would rise only as the moon passes round the earth; what then causes the tides to rise twice in 24 hours? When it is high water under the moon by her attraction, what is the cause of high water on the opposite side of the earth at the same time?—738. Why are the tides about 50 minutes later every day?—739. What produces spring tides? Where must the moon be in respect to the sun to produce spring tides?—740.

What is the occasion of neap tides?—741. Why are not the tides at their greatest height when the moon is at its meridian?—742. What is the average height of tides? State some exceptions to this rule.

743. How is the situation of places on the surface of the earth determined, as to north and south? How, as to east and west? How is a circle divided? What are the signs of the divisions?—744. What is the difference between a geographical mile and the British statute mile?—745. What is latitude? How many degrees of latitude are there? How far do the lines of latitude extend? What is meant by north and south latitude? What are the parallels of latitude?—746. What is longitude? How many degrees of longitude are there, east or west? What is the latitude of any place?—747. What is the longitude of a place?—748. Why are the degrees of latitude reckoned from the equator?

748. What is said concerning the places from which the degrees of longitude have been reckoned? What is the inconvenience of estimating longitude from a place in each country? From what place is longitude reckoned in Europe and America?—749. How is the latitude of a place determined? Give an example of the method of finding the latitude of the same place at different seasons of the year.—750. When must the sun's declination from the equator be added to, and when subtracted from, his meridian altitude?—751. Why is there more difficulty in ascertaining the degrees of longitude than of latitude?—752. How many degrees of longitude does the surface of the earth pass through in an hour? Suppose it is noon at any given place, what o'clock will it be 15 degrees to the east of that place? Explain the reason. How may longitude be determined by an eclipse?—753. Explain the principles on which longitude is determined by the chronometer.—754. Suppose the captain finds by his chronometer that it is twelve o'clock, where he is, six hours later than at Greenwich, what then would be his longitude? Suppose he finds it to be twelve o'clock four hours earlier, where he is, than at Greenwich, what then would be his longitude?

755. Why are the stars called fixed? How may the stars be distinguished from the planets?—756. The stars are divided into classes according to their magnitudes; how many classes are there? How many stars may be seen with the naked eye in the whole firmament? State the suggestion of Kepler with reference to the classification of the stars.—757. What is the computed distance of the nearest fixed stars from the earth? How long would it take light to reach us from the fixed stars? How large would our sun appear at the distance of the fixed stars? What is said concerning the difference of the distance between the earth and the fixed stars at different seasons of the year, and of their different appearance in consequence?—758. How may the distances of the fixed stars be inferred by the long absence and return of comets?—759. On what grounds is it supposed that the fixed stars are suns to other worlds?—760. What is the milky way? How is it divided?

—761. What are periodical stars? Describe the periodicity of one of these.—762. What are temporary stars? Give an account of one of these.

763. What is a comet?—764. In what kind of orbit do comets move? —765. What number of comets are supposed to belong to our system? How many have had the elements of their orbits estimated by astronomers? How many are there whose periods of return are known? What is said of the comet of 1682?—766. How many comets are described as moving round the sun from west to east, and how many from east to west?—767. What is the general appearance presented by a comet? What opinions have been entertained of their nature?—768. State the periodicities of the comets of Halley, Encke, and Biela.—769. What is the amount of probability that a comet will ever come into collision with the earth?

CHAP. X.

OF ELECTRICITY.

770. *General remarks.*—Electricity is one of those powers which appear to exist universally throughout nature, and to be employed in her most important and secret operations. It is an agent of great force, and affects all kinds of matter. It is seen in its most intense activity in lightning; in a feebler and more diffused form, it traverses the upper regions of the atmosphere, under the denomination of the *northern lights;* and it is probably present in all forms of matter. It influences the *chemical* relations of all bodies, and has been considered by some of the most distinguished chemists as the cause of all chemical phenomena. It is the source of perhaps the most intense light and heat which can be produced by artificial means. It is the cause of magnetism, and exerts a most powerful influence on the animal economy. Its phenomena appear to depend upon *two energies*, or two kinds of electricity, which usually exist in a state of *equilibrium;* and in this state its peculiar effects are not called into action. This equilibrium is, however, disturbed by a variety of causes, and the existence of these energies is then manifested by a great variety of remarkable effects. Under the operation of these causes, material substances are found to possess different capacities for carrying or conveying away the electric energies, which may thus be partially separated and kept apart from each other. Hence, if two bodies be charged in excess with the *same* kind of energy, and brought near each other, repulsion takes place between them ; while, if charged with the *two different* energies, they attract each other. In this disturbance of the electric *equilibrium*, the energies, which are supposed to be to a certain extent, though not entirely, separated from each other, have a tendency to restore the *equilibrium* between themselves, a portion of the energy of one body passing to the other, and receiving a corresponding portion of the antagonist energy. When the *equilibrium* is restored, each body contains the same quantity of each energy which it possessed before their disturbance. In passing from one body to another, considerable violence is produced, and rendered visible under the form of flashes and

sparks. This communication of electricity is accompanied by painful shocks, convulsive motions, and even death in animals through which it passes; and exhibits, on a small scale, all the effects of lightning.

771. The term electricity is derived from ἤλεκτρον, *electron*, the Greek name of amber, because it was known to the ancients, that, when this substance was rubbed or excited, it attracted or repelled small light bodies, and it was then unknown that other substances, when excited, would do the same. If a piece of amber, sealing-wax, or glass with a smooth surface, be rubbed with a dry woollen cloth, and then brought near a light body, as a feather, a cork ball, or a fragment of paper, these bodies are *attracted* towards the substance which has been rubbed, and which is now said to be *electrically excited.* All bodies, capable of being excited, are called *electrics:* the principal of these are amber, gumlac, resin, sulphur, glass, talc, the precious stones, silk, the fur of quadrupeds, and almost all vegetable substances (excepting charcoal), which have been thoroughly deprived of moisture, as baked wood and perfectly dry paper. After a certain time, which varies in different substances, the attracted body is *repelled* from the electric; and, on again presenting it to the electric, it is again repelled, provided it has touched no other body in the meantime. It is also found that two bodies, which have been in contact with the same electric, mutually repel each other.

772. *Electroscopes.*—"Various instruments have been devised for exhibiting distinctly the attractive and repulsive agencies of electricity, and for obtaining indications of its presence, when it exists only in a feeble degree. Instruments, for this purpose, are termed *electroscopes.* 1. One of the simplest instruments of this kind consists of a metallic needle, terminated at each end by a light pith ball, which is covered with gold leaf, and supported horizontally at its centre by a fine point. When a stick of sealing-wax, or a glass tube, is excited, and then presented to one of these balls, the motion of the needle on its pivot will indicate the electrical influence. 2. If an excited substance be brought near a ball made of pith, or cork, suspended by a silk thread,

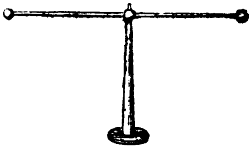


Fig. 247.

the ball will, in the first place, approach the electric, as at A, Fig. 248, indicating an attraction towards it, and if the position of the electric will allow, the ball will come into contact with the electric, and adhere to it for a short time, and will then recede from it, showing that it is repelled, as at B. If now the ball which had touched the electric, be brought near another ball, which has had no communication with an excited substance, these two balls will attract each other, and come into contact; after which they will repel each other, as in the former case. It appears, therefore, that the excited body, as the stick of sealing-wax, imparts a portion of its electricity to the ball, and that when the ball is also electrified, a mutual repulsion takes place between them. Afterwards, the ball, being electrified by contact with the electric, when brought near another ball not electrified, transfers a part of its electrical influence to that, after which these two balls repel each other, as in the former instance. Thus, when one substance has a greater or less quantity of electricity than another, it will attract the other substance, and when they are in contact, will impart to it a portion of this superabundance; but when they are both equally electrified, both having more or less than their natural quantity of electricity, they will repel each other.

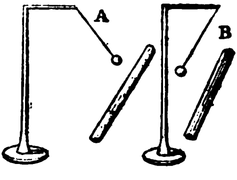


Fig. 248.

773. *Theories of electricity.*—"To account for these phenomena, two theories have been advanced, one by Dr Franklin, who supposed there is only one electrical fluid; the other by Du Fay, who supposed that there are two distinct fluids.

774. "Dr Franklin supposed that all terrestrial substances were pervaded with the electrical fluid, and that by exciting an electric, the equilibrium of this fluid was destroyed, so that one part of the excited body contained more than its natural quantity of electricity, and the other part less. If in this state a conductor of electricity, as a piece of metal, be brought near the excited part, the accumulated electricity would be imparted to it, and then this conductor would receive more than its natural quantity of the electric fluid. This he called *positive* electricity. But if a conductor be connected with that part which has less than its ordinary

share of the fluid, then the conductor parts with a share of its own, and therefore will then contain less than its natural quantity. This he called *negative* electricity. When one body *positively*, and another *negatively* electrified, are connected by a conducting substance, the fluid rushes from the positive to the negative body, and the equilibrium is restored. Thus bodies which are said to be positively electrified contain more than their natural quantity of electricity, while those which are negatively electrified contain less than their natural quantity.

775. "The other theory is explained thus. When a piece of glass is excited, and made to touch a pith ball, as above stated, then that ball will attract another ball, after which they will mutually repel each other, and the same will happen if a piece of sealing-wax be used instead of the glass. But if a piece of excited glass, and another of wax, be made to touch two separate balls, they will attract each other; that is, the ball which received its electricity from the wax will attract that which received its electricity from the glass, and will be attracted by it. Hence Du Fay concludes that electricity consists of two distinct fluids, which exist together in all bodies—that they have a mutual attraction for each other—that they are separated by the excitation of electrics, and that when thus separated, and transferred to non-electrics, as to the pith balls, their mutual attraction causes the balls to rush towards each other. These two principles he called *vitreous* and *resinous* electricity; the vitreous being obtained from glass, and the resinous from wax, and other resinous substances."

COMMUNICATION OF ELECTRICITY.

776. Electricity may be *communicated* from one body to another. The capacity of bodies for carrying, or conveying away, electricity, is called their conducting or non-conducting power. 1. The best *conductors* are the metals; of these, silver and copper are the best; next follow gold, zinc, platinum, iron, tin, lead, antimony, and bismuth; this is very nearly the order in which these metals possess their conducting power for heat. Then follow, successively, charcoal, acid liquids, solutions of salt, animal substances, water, and gases which have been rarefied by heat or diminution of pressure, or charged with a large quantity of moisture. Upon the principle of *conduction*, copper rods are employed

for protecting buildings from the effects of lightning; these are fixed above the building, and continued uninterruptedly downwards to the moist ground or the nearest water. In large buildings, many rods should be employed; or, if few, they should be elevated to a certain height above the building, since a rod only protects a circle round it, the radius of which is equal to twice its length above the building, 2. The principal *non-conductors* are sulphur, resinous substances, glass, air, wood, paper, hair, silk, feathers, and wool. It is always found that *electrics* are *non-conductors*, and that *conductors*, on the other hand, are *non-electrics;* the two properties, of being electrically excited, and of conducting electricity, being incompatible with each other.

777. The conducting power of most bodies is influenced by changes of *temperature* and of *form.* Thus, if the temperature of water be raised, its conducting power is increased; if reduced to the point of congelation, its conducting power is diminished; at — 13° Fahr. it ceases altogether. Charcoal is found to transmit electricity with more facility when hot, than when cold. Glass, which is a non-conductor when cold, becomes a tolerably good conductor when heated to redness. Mr Faraday discovered that various substances which do not conduct when solid, conduct readily when fused by heat. In some substances, the power of conduction is influenced by their being reduced to powder. Thus, *snow* exhibits a lower conducting power than *ice* of the same temperature; powdered charcoal presents the same phenomenon; whilst the conducting power of glass and sulphur is *raised* by their being pulverized. Many bodies are deprived of their power of conduction, when reduced to a state of dryness; this is the case with air and gases, and with recent animal and vegetable substances.

778. The communication of electricity from one body to another is effected by means of metallic wires. It is said to move in a current, from an overcharged to an undercharged body; this current is termed the *electric circuit.* If the communication be arrested by bad conductors, the circuit is said to be *broken;* it is at this point of the circuit that bodies are placed, through which the electrical current is to be passed. Electricity does not penetrate into the substance of bodies: in smooth spherical bodies it is distributed equally over the surface; in other bodies it is accumulated at particular points of the surface. Pointed bodies convey away electri-

city much more readily than spherical bodies. Lightning, in its course, strikes the highest pointed objects; pointed rods are, therefore, the best for protecting buildings. When an electrified body is supported on a bad conductor, as glass, it is said to be *insulated.*

EXCITATION OF ELECTRICITY.

779. *Excitation of electricity by mechanical action.*—The electric *equilibrium* is readily disturbed by *friction.* The nature of the excitement is much influenced by the state of the surface rubbed, and by the substance employed as a rubber. Thus, smooth glass is rendered *positive* by being rubbed with a woollen cloth, but rough glass is rendered *negative* by being rubbed with the same substance; sealing-wax is rendered *positive* by metallic substances, but *negative* by hare's skin, and, indeed, by almost every thing else. The following table exhibits the results of numerous experiments:—

Substances excited.	Kind of Electricity.	Material forming the rubber.
Back of a cat	Positive	Every substance hitherto tried.
Smooth glass	Positive	Do. except the back of a cat.
Rough glass	Positive	Dry oiled silk, sulphur, metals
	Negative	Woollen cloth, paper, wax, human hand.
Tourmaline	Positive	Amber, a current of air.
	Negative	Diamond; the human hand.
Hare skin	Positive	Metals, silk, leather, the hand.
	Negative	The finer furs.
White silk	Positive	Black silk, the metals, &c.
	Negative	Paper, hair, the hand, &c.
Black silk	Positive	Sealing-wax.
	Negative	Furs, metals, the hand.
Sealing-wax	Positive	Metals.
	Negative	Furs, the hand, leather, cloth, paper.
Baked wood	Positive	Silk.
	Negative	Flannel.

780. "When large quantities of the electric fluid are wanted for experiment, or for other purposes, it is procured by an *electrical machine.* These machines are of various forms, but all consist of an *electric* substance, of considerable dimensions; the *rubber* by which this is excited; the *prime conductor*, on which the electric matter is accumulated; the *insulator*, which prevents the fluid from escaping; and machinery by which the

electric is set in motion. Fig. 249 represents such a machine, of which A is the electric, being a cylinder of glass; B, the prime conductor, R, the rubber or cushion, and C, a chain connecting the rubber with the ground. The prime conductor is supported by a standard of glass. Sometimes also the pillars which support the axis of the cylinder, and that to which the cushion is attached, are made of the same material. The prime conductor has several wires inserted into its side, or end, which are pointed, and stand with the points near the cylinder. They receive the electric fluid from the glass, and convey it to the conductor. The conductor is commonly made of sheet brass, there being no advantage in having it solid, as the electric fluid is always confined entirely to the surface. Even paper, covered with gold leaf, is as effective in this respect, as though the whole was of solid gold. The cushion is attached to a standard, which is furnished with a thumb-screw, so that its pressure on the cylinder can be increased or diminished. The cushion is made of leather, stuffed, and at its upper edge there is attached a flap of silk, F, by which a greater surface of the glass is covered, and the electric fluid thus prevented, in some degree, from escaping. The efficacy of the rubber in producing the electric excitation is much increased by spreading on it a small quantity of an amalgam of tin and mercury, mixed with a little lard, or other unctuous substance.

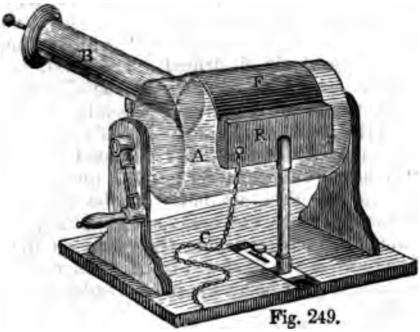


Fig. 249.

781. "The manner in which this machine acts may be inferred from what has already been said, for when a stick of sealing-wax, or a glass tube, is rubbed with the hand, or

a piece of silk, the electric fluid is accumulated on the excited substance, and therefore must be transferred from the hand, or silk, to the electric. In the same manner, when the cylinder is made to revolve, the electric matter, in consequence of the friction, leaves the cushion, and is accumulated on the glass cylinder: that is, the cushion becomes negatively, and the glass positively electrified. The fluid, being thus excited, is prevented from escaping by the silk flap, until it comes to the vicinity of the metallic points, by which it is conveyed to the prime conductor. But if the cushion is insulated, the quantity of electricity obtained will soon have reached its limit, for when its natural quantity has been transferred to the glass, no more can be obtained. It is then necessary to make the cushion communicate with the ground, which is done by laying the chain on the floor or table, when more of the fluid will be accumulated by further excitation, the ground being the inexhaustible source of the electric fluid.

782. "If a person who is insulated take the chain in his hand, the electric fluid will be drawn from him, along the chain to the cushion, and from the cushion will be transferred to the prime conductor, and thus the person will become negatively electrified. If, then, another person, standing on the floor, hold his knuckle near him who is insulated, a spark of electric fluid will pass between them, with a crackling noise, and the equilibrium will be restored; that is, the electric fluid will pass from him who stands on the floor to him who stands on the stool. But if the insulated person take hold of a chain, connected with the prime conductor, he may be considered as forming a part of the conductor, and therefore the electric fluid will be accumulated all over his surface, and he will be positively electrified, or will obtain more than his natural quantity of electricity. If, now, a person standing on the floor touch this person, he will receive a spark of electrical fire from him, and the equilibrium will again be restored.

783. "If two persons stand on two insulated stools, or if they both stand on a plate of glass, or a cake of wax, the one person being connected by the chain with the prime conductor, and the other with the cushion, then, after working the machine, if they touch each other, a much stronger shock will be felt than in either of the other cases, because the difference between their electrical states will be greater,

the one having more and the other less than his natural quantity of electricity. But if the two insulated persons both take hold of the chain connected with the prime conductor, or with that connected with the cushion, no spark will pass between them on touching each other, because they will then both be in the same electrical state.

784. "We have seen, Fig. 248, that the pith ball is first attracted and then repelled, by the excited electric, and that the ball so repelled will attract, or be attracted by, other substances in its vicinity, in consequence of having received from the excited body more than its ordinary quantity of electricity. These alternate movements are amusingly exhibited, by placing some small light bodies, such as the figures of men and women, made of pith or paper, between two metallic plates, the one placed over the other, as in Fig. 250, the upper plate communicating with the prime conductor, and the other with the ground. When the electricity is communicated to the upper plate, the little figures, being attracted by the electricity, will jump up, and strike their heads against it, and having received a portion of the fluid, are instantly repelled, and again attracted by the lower plate, to which they impart their electricity, and then are again attracted, and so fetch and carry the electric fluid from one to the other, as long as the upper plate contains more than the lower one. In the same manner, a tumbler, if electrified on the inside, and placed over light substances, as pith balls, will cause them to dance for a considerable time.

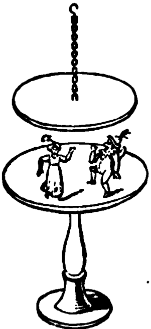


Fig. 250.

785. "This alternate attraction and repulsion, by moveable conductors, is also pleasingly illustrated by a ball, suspended by a silk string between two bells of brass, Fig. 251, one of the bells being electrified, and the other communicating with the ground. The alternate attraction and repulsion move the ball from one bell to the other, and thus produce a continual ringing. In all these cases,

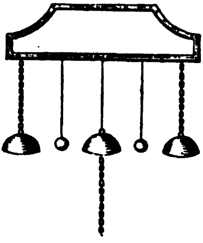


Fig. 251.

the phenomena will be the same, whether the electricity be positive or negative: for two bodies, being both positively or negatively electrified, repel each other, but if one be electrified positively, and the other negatively, or not at all, they attract each other. Thus, a small figure, in the human shape, with the head covered with hair, when electrified either positively or negatively, will exhibit an appearance of the utmost terror, each hair standing erect, and diverging from the other, in consequence of mutual repulsion. A person standing on an insulated stool, and highly electrified, will exhibit the same appearance. In cold, dry weather, the friction produced by combing a person's hair, will cause a less degree of the same effect. In either case the hair will collapse, or shrink to its natural state, on carrying a needle near it, because this conducts away the electric fluid."

786. *Excitation by change of temperature.*—Electricity is excited in bodies by change of *temperature.* Haüy discovered this fact in the case of unsymmetrical crystals: the variety of tourmaline, called isogone, exhibits no sign of electricity at 105° Fahr.; but after immersion in boiling water, its three-sided pyramid possesses *negative*, its six-sided pyramid *positive*, electricity; this property continues for six hours after the temperature of the crystal has fallen to the former degree. Dr Seebeck, of Berlin, found that certain metallic rods, which were differently heated at their extremities, exhibited a disturbance of the electric equilibrium; and this has been shown by Dr Cumming to be true of all metals. The facts connected with the excitation of electricity by heat belong to the department of *thermo-electricity*, and are described in larger treatises on Natural Philosophy.

787. *Excitation by change of form.*—Change of temperature is accompanied by change of *form*, and this is considered a source of electricity. If melted sulphur be poured into a metallic cup, and removed after it has become solid, the sulphur is found to be *negative*, the cup *positive;* or, if a few drops of water be evaporated by being poured into a hot iron vessel, electrical excitement is exhibited. These facts are, however, referred by Pouillet to the *chemical* action with which they are attended. Turner observes that he repeatedly noticed free electric excitement on pouring a solution of chloride of sodium or sulphate of soda into a heated platinum crucible, and also when pure water was dropped on red-hot iron or a glowing cinder; but that he as constantly failed of

procuring any indication, when pure water was evaporated on platinum. The latter fact is, however, maintained by Mr. Harris.

788. *Excitation by chemical action.*—The excitement produced by the electrical machine might be supposed to depend upon friction; but it is found to be much more connected with *chemical action* than with friction. The amalgam, with which the rubber is coated, becomes *oxidized* on exposure to the air, and the excitement of the machine appears to depend mainly on this *oxidation* of the metals. Hence, it is found that the only useful amalgams for this purpose, are those which are readily disposed to oxidize, as zinc and tin; whereas silver and platinum, being indisposed to this effect, produce no electrical excitement. And it is further found that an electrical machine, when surrounded with carbonic acid, ceases to act, though it immediately recovers its action on readmitting the atmospheric air. Electrical excitement is also exhibited by the process of *combustion:* charcoal itself is *negative*, but the gas arising from this substance, when burning, is *positive.* The combustion of hydrogen, alcohol, and other inflammable substances, affords similar indications of electricity.

789. *Excitation by contact.*—Electricity is said to be produced by *contact* of dissimilar bodies, particularly of metals, as zinc and copper, of which the latter exhibits negative, the former positive, electricity. This is the basis of Volta's theory of galvanism; but the results are ascribed by others to chemical action and friction. The effect produced by the contact of zinc and copper is attributed by De la Rive to slight oxidation produced by moisture and oxygen of the air acting on the zinc, no such result being obtained when the metals are surrounded with hydrogen or nitrogen; a still greater degree of excitement is effected by employing a more oxidable metal than zinc. Faraday concludes that the opposite evidence, adduced by Volta and others, must be rejected; and that the only remaining facts in favour of Volta's opinion are derived from certain chemical agencies evinced by metals during contact.

790. *Excitation by induction.*—Electricity is exhibited by bringing an unelectrified body into the neighbourhood of an electrified body; such electricity is said to be *induced*, or excited by *induction.* From what has been already said of the mutual attraction and repulsion of the two electricities,

it will readily be inferred that an excited body tends to induce in an unexcited body an electrical state opposite to its own. The electricity, for instance, of a positive body repels the corresponding electricity of a neighbouring body to its further extremity, and attracts the opposite electricity to its near extremity. This phenomenon is illustrated by the annexed figure. A B is an unexcited conductor, supported on an insulating glass leg *b c*, while C is a body containing positive electricity, similarly insulated, and placed near the conductor. The positive electricity of C repels the corresponding electricity of A B to its further extremity, and induces the opposite electricity to its near extremity. The relative position of the two fluids is indicated by the signs + and —, the former denoting the *positive*, the latter the *negative*, electricity. On removing the body C, the equilibrium of the body A B is restored, neither of the bodies having gained or lost any thing by the experiment. If, on the other hand, the repelled electricity of A B be neutralized by communication with the ground, and if during the induction the connexion be broken, this body is left with an excess of negative electricity.

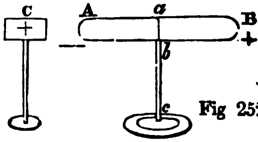


Fig 252.

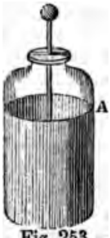


Fig. 253.

791. The action of the *Leyden jar* depends on the principle of *induced electricity*. It is a contrivance by which electricity can be accumulated in larger quantity than in the prime conductor. A glass jar with a wide mouth is coated both internally and externally with tin-foil to within a third of the top, the upper part being left naked to prevent a spontaneous discharge, or the passage of the electric fluid from one coating to the other. The aperture is closed by a disc of dry wood, through which is passed a metallic rod, communicating with the inner coating, and terminating externally in a brass knob. On placing the knob in contact with the prime conductor of an excited electrical machine, while the outer coating communicates with the ground, the interior of the jar becomes positively, the exterior negatively, electrified. If the jar be insulated, and the knob be placed near the prime conductor, without actual contact with it, while an uninsulated conductor is placed at an equal distance from

the outer coating, electric sparks of equal size and number will pass between the two intervals, and the interior and exterior of the jar will maintain the same condition as they had before; but no charge will be received, if, when the inner coating communicates with the prime conductor, the outer coating be strictly insulated. From these facts it is concluded that the interior of the jar becomes positive by communicating negative electricity to the prime conductor; and that the exterior then becomes negative by the loss of a quantity of positive electricity equal to that on the interior. By connecting together a sufficient number of Leyden jars, a large quantity of the electric fluid may be accumulated. For this purpose, all the interior coatings are made to communicate with each other by metallic rods, which finally terminate in a single knob; communication is also established between their outer coatings by placing them in a box lined with tinfoil; the whole series may then be charged as if they formed but one jar; and they may all be discharged at the same moment. Such an arrangement is called an *electrical battery*.

792. When it is desired to discharge a jar, or a battery, a communication between the two surfaces is effected by means of a *discharging rod*. This instrument consists of two bent metallic rods, each of them terminating at one end in a brass knob, and connected at the other end by a joint, which is fixed to a glass handle. The brass rods being opened to a proper distance, the knob of one is brought in contact with the outer coating of the jar, while that of the other is applied to the knob of the jar; the discharge is thus effected, and the equilibrium restored between the interior and exterior surfaces of the jar. When it is desired to pass the electric fluid, thus obtained, through any substance, this must be placed between two metallic conductors, the one communicating with the outer, the other with the inner coating of the jar, or battery. Such an arrangement is called an electrical circuit.

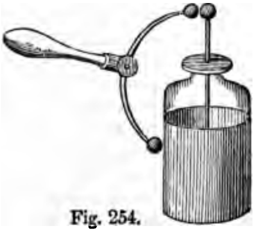


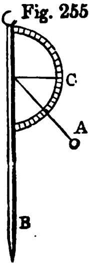
Fig. 254.

793. "When a person takes the electrical shock in the usual manner, he merely takes hold of a chain connected with

the outside coating, and, the battery being charged, touches the knob with his finger, or with a metallic rod. On making this circuit, the fluid passes through the person from the positive to the negative side. Any number of persons may receive the electrical shock, by taking hold of each other's hands, the first person touching the knob, while the last takes hold of a chain connected with the external coating. In this manner, hundreds, or perhaps thousands of persons, will feel the shock at the same instant, there being no perceptible interval in the time when the first and the last person in the circle feel the sensation excited by the passage of the electric fluid.

794. "The atmosphere always contains more or less electricity, which is sometimes positive, and at others negative. It is, however, most commonly positive, and always so when the sky is clear, or free from clouds or fogs. It is always stronger in winter than in summer, and during the day than during the night. It is also stronger at some hours of the day than at others; being strongest about nine o'clock in the morning, and weakest about the middle of the afternoon. These different electrical states are ascertained by means of long metallic wires extending from one building to another, and connected with electrometers."

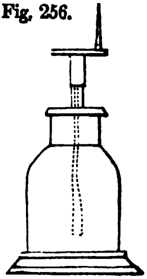
Fig. 255.



795. *Electrometer.*—It is necessary, in this place, to point out the distinction between the *quantity*, and the *intensity*, of electricity which may be called into action. The electrical machine develops electricity of great *intensity*, but of sparing *quantity;* the galvanic battery, on the other hand, produces a large *quantity* of electricity, but it is of feeble *intensity*. The term *intensity*, therefore, denotes the *degree* of excitement exhibited by an electrified body. Various instruments, called *electrometers*, have been contrived for measuring the intensity with which attractions and repulsions of this kind are excited; the intensity being indicated by the distance to which a substance of determinate size and form is repelled. 1. One of these instruments, which is called the *quadrant electrometer*, acts by the divergence of a slender rod of light wood A, terminated by a pith ball, from a stem of wood B, which is screwed into the prime conductor. An ivory quadrant, or semicircle C, is fixed to the upper part of the stem, having its centre coinciding with the axis of motion of the rod, and serving as a gra-

duated scale. The degree of intensity is indicated by the distance to which the ball is repelled from the stem. 2. Another of these instruments, called the *gold leaf electrometer*, affords a most delicate test of the nature of electrical excitement. It consists of a glass cylinder cemented below upon a brass plate, and covered above by another plate of the same material. Two pieces of gold leaf are suspended from the upper plate, and a slip of tinfoil is fastened on each side of the glass case to carry off the electricity when the gold leaves diverge so far as to come in contact with them.

Fig. 256.



796. " It was proved by Dr Franklin, that the electric fluid and *lightning* are the same substance, and this identity has been confirmed by subsequent writers on the subject. If the properties and phenomena of lightning be compared with those of electricity, it will be found that they differ only in respect to degree. Thus, lightning passes in irregular lines through the air; the discharge of an electrical battery has the same appearance. Lightning strikes the highest pointed objects; takes in its course the best conductors; sets fire to non-conductors, or rends them in pieces; and destroys animal life; all of which phenomena are caused by the electric fluid.

797. " Buildings may be secured from the effects of lightning, by fixing to them a metallic rod, which is elevated above any part of the edifice and continued to the moist ground, or to the nearest water. Copper, for this purpose, is better than iron, not only because it is less liable to rust, but because it is a better conductor of the electric fluid. The upper part of the rod should end in several fine points, which must be covered with some metal not liable to rust, such as gold, platina, or silver. *No protection is afforded by the conductor unless it is continued without interruption from the top to the bottom of the building, and it cannot be relied on as a protector, unless it reaches the moist earth, or ends in water connected with the earth.* Conductors of copper may be three-fourths of an inch in diameter, but those of iron should be at least an inch in diameter. In large buildings, complete protection requires many lightning rods, or that they should be elevated to a height above the building in propor-

tion to the smallness of their numbers, for modern experiments have proved that a rod only protects a circle around it, the radius of which is equal to twice its length above the building."

GALVANISM, OR VOLTAIC ELECTRICITY.

798. *Simple voltaic circle.*—The effect of electricity upon animals was first noticed by Galvani. He found that when two metals, as zinc and silver, the one in contact with the crural nerve of a recently killed frog, the other with the muscles to which the nerve is distributed, are brought into contact with each other, muscular contraction ensued. This fact gave rise to the science called *animal electricity*, or *galvanism*. This phenomenon was attributed by Volta to the disturbance of the electric equilibrium by the contact of two dissimilar metals. The identity of the common and the galvanic electricities was proved by the discovery of the voltaic pile, and the science has from that pèriod been termed by some writers, *voltaism*, or *voltaic electricity*.—If a plate of zinc and a plate of copper be immersed to a certain depth in a vessel containing dilute sulphuric acid, and connected together by direct contact, as in Fig. 257, a current of positive electricity passes uninterruptedly from the zinc through the liquid to the copper, and from the copper to the zinc, in the direction of the arrows. Such an arrangement is termed a *simple voltaic circle*.

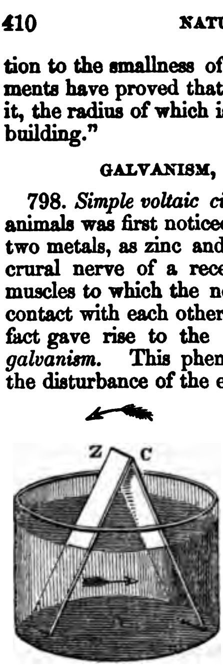


Fig. 257.

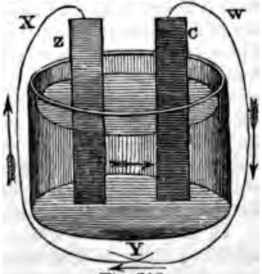


Fig. 258.

799. "The same effect will be produced, if, instead of allowing the metallic plates to come in contact, a communication between them be made by means of wires, as shown by Fig. 258. In this case, as well as in the former, the electricity proceeds from the zinc, z, which is the positive side, to the copper, c, being

conducted by the wires in the direction shown by the arrows. The completion of the circuit by means of wires, enables us to make experiments on different substances by passing the galvanic influence through them, this being the method employed to exhibit the effects of galvanic batteries, and by which the most intense heat may be produced."

800. *Compound voltaic circle.*—It is necessary to combine a series of these plates, if we desire to produce more decided effects. "The *pile* of Volta was one of the earliest means by which a compound galvanic series was exhibited. This consisted of a great number of silver or copper coins, and thin pieces of zinc of the same dimensions, together with circular pieces of card, wet with an acid, piled, one series above another, in the manner shown in Fig. 259. The student should be informed that it makes no difference what the metals are which form the galvanic series, provided one be more easily oxidated, or dissolved in an acid, than the other, and that the more oxidable one always forms the positive side. Thus, copper is negative when placed with zinc, but becomes positive with silver. The three substances composing the *pile*, zinc, silver, wet card, and marked z, s, w, succeed each other in the same order throughout the series, and its power is equal to a single circle, multiplied by the number of times the series is repeated.

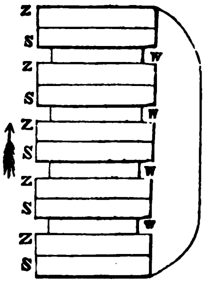


Fig. 259.

801. *Trough battery.*—"The galvanic pile is readily constructed, and answers for small experiments; but when large quantities of electricity are required, other means are resorted to, and, among these, what is termed the *trough battery*, is the most convenient and efficacious. The zinc and copper plates are fastened to a slip of mahogany wood, and are united in pairs by a piece of metal soldered to each. Each pair is so placed as to enclose a partition of the trough between them, each cell containing a plate of zinc connected with the copper plate of the succeeding cell, and a plate of copper joined with the zinc plate of the preceding cell. This arrangement will be understood by Fig. 260, where the plates P are connected in the order described, and below

them the trough T, to contain the acid into which the plates are to be plunged. The trough is made of wood, with partitions of glass, or, what is better, of Wedgewood's ware. Each trough contains eight or ten cells, which being filled with diluted acid, the plates are suspended and let down into them by means of a pulley. The advantage of this method is, that the plates can be elevated at any moment, and are easily kept clean from rust, without which the galvanic action becomes feeble."

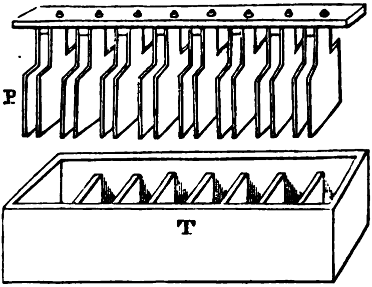


Fig. 260.

802. The liquid usually employed consists of 1 part of acid to 15 or 25 of water, when a very strong charge is required; and of 1 part of acid to 80 or 100 of water, for a weak charge. Nitric acid is preferred for the evolution of heat and light, but it is seldom employed alone, being commonly mixed with from one-tenth to a half of sulphuric acid. Saline solutions, and even common water, are sufficient for some purposes, but they are exceedingly feeble when compared with the preceding mixtures. In compound galvanic circles, the zinc plate which terminates them at one end is called the *positive pole* of the battery; and the copper plate at the other extremity, the *negative pole*. Various other combinations may be employed; but those already described are the most practically convenient.

803. The phenomena of the *pile* were afterwards referred by Wollaston to the development of electricity by *chemical* agency. It is found that the zinc is always oxidized; that the effects of the pile are proportionate to the degree of oxidation of the metal; and that without oxidation no sen-

sible effects are produced. Wollaston therefore inferred that the liquid oxidized the zinc, and conveyed the developed electricity to the copper, the contact between the metals merely furnishing the means of completing the circle.

804. The *electro-chemical* theory of Davy is intermediate between those of Volta and Wollaston, and is founded on the assumption that electrical and chemical attractions depend upon the *same* agent. According to this view, the particles of chemical substances possess natural electric energies, chemical combination being the result of electric attraction between oppositely excited particles, while chemical decomposition is effected by the action of other particles of a higher electric energy. In applying this theory to the *pile*, Davy considered that electricity is developed in the first instance by metallic contact, and that it is afterwards maintained by chemical action. "The progress of inquiry," says Dr Turner, "since these theories first came into notice, has gradually given more and more support to the views of Wollaston, and has at last, I apprehend, established them to the entire exclusion of the theory of Volta. The very fundamental position, that electricity is excitable as a primary result by the contact of different substances, is warmly contested, and, as some think with strong reason, has been disproved; but admitting, for the sake of argument, that a *small* effect, which is all that can now be contended for, may thus be produced, it is altogether insignificant when contrasted with the astonishing phenomena exhibited by a voltaic circle."

EFFECTS OF ELECTRICITY.

805. *Production of heat and light.*—On applying the hand or any conducting substance to the prime conductor of an electrical machine, a spark is produced. A still more brilliant spark is observed on discharging the Leyden jar. In *common electricity*, there is no production of heat, when the fluid moves through a perfect conductor, and meets with no obstruction; but in its passage through imperfectly conducting substances, both heat and light are developed. Light and heat are evolved by *voltaic batteries* of sufficient intensity. As the wires are brought together, a spark appears before actual contact has taken place, owing to the *transference* of electricity through the air; a spark also appears every time the contact of the wires is broken. The evolution of heat may be perceived on uniting the poles of a bat-

tery in a vessel of water containing a thermometer: the temperature of the water is soon raised, and, on continuing the experiment, will reach the boiling point. If the current be conveyed along metallic wires, or wires terminated by charcoal, the wires become fused, the charcoal presents a vivid white light; in the latter case, on withdrawing the extremities of the conductors from each other, to an interval of about four inches, an arch of light of dazzling brilliancy appears between them. This phenomenon is represented in the subjoined figure, in which *a* and *b* are the poles of the battery

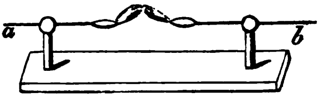


Fig. 261.

with pieces of charcoal attached to them, and between these is the ascending arch of light. In the battery of the Royal Institution, any substance held in this arch became instantly ignited; platinum, one of the most infusible of all the metals, melted in it as readily as wax in a candle; quartz, sapphire, magnesia, and lime, became fused; and points of diamond and plumbago rapidly disappeared, as if they had been evaporated by heat. The *heating* effects of voltaic electricity appear to depend on the conducting power of the substance employed, the heat being in an inverse ratio to its conducting power. This is strikingly shown in passing the current through a chain composed of alternate links of platinum and silver: the platinum will be intensely ignited, while the silver will be scarcely warmed. If the poles of the battery are made to terminate in metallic leaves, instead of charcoal, the leaves will burn with various *colours:* gold yields a white light tinged with blue; silver, a brilliant emerald-green light; copper, a bluish-white light with red sparks; lead, a purple light; zinc, a brilliant white light inclining to blue and fringed with red. The light produced by voltaic electricity cannot be attributed to combustion, as it occurs in gases which contain no oxygen, and even under water; it is also found that neither the gas nor the charcoal has undergone any chemical change. In experiments of this kind with the voltaic battery, a small number of very large plates is found to be more effectual than a large number of small plates.

806. "The passage of the electric fluid through a perfect conductor is never attended with light, or the crackling noise, which is heard when it is transmitted through the air, or along the surface of an electric. Several curious experiments illustrate this principle; for if fragments of tin-foil, or other metal, be pasted on a piece of glass, so near each other that the electric fluid can pass between them, the whole line thus formed with the pieces of metal, will be illuminated by the passage of the electricity from one to the other. In this manner, figures or words may be formed, as in Fig. 262, which, by connecting one of its ends with the prime conductor, and the other with the ground, will, when the electric fluid is passed through the whole, in the dark, appear one continuous and vivid line of fire.

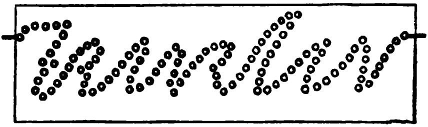


Fig. 262.

807. " Electrical light seems not to differ, in any respect, from the light of the sun, or of a burning lamp. Wollaston observed, that when this light was seen through a prism, the ordinary colours arising from the decomposition of light were obvious.

808. "The brilliancy of electrical sparks is proportional to the conducting power of the bodies between which it passes. When an imperfect conductor, as a piece of wood, is employed, the electric light appears in faint, red streams; while, if passed between two pointed metals, its colour is of a more brilliant red. Its colour also differs, according to the kind of substance from, or to which, it passes, or it is dependent on peculiar circumstances. Thus, if the electric fluid passes between two polished metallic surfaces, its colour is nearly *white;* but if the spark be received by the finger from such a surface, it will be *violet.* The sparks are *green*, when taken by the finger from a surface of silvered leather; *yellow*, when taken from finely powdered charcoal; and *purple*, when taken from the greater number of imperfect conductors.

809. "When the electric fluid is discharged from a point, it is always accompanied by a current of air, whether the electricity be positive or negative. The reason of this ap-

pears to be, that the instant a particle of air becomes electrified, it repels, and is repelled by the point from which it received the electricity. Several curious experiments are made on this principle. Thus, let two or more cross wires, as in Fig. 263, be suspended on a pivot, each having its points bent in contrary directions, and electrified by being placed on the prime conductor of a machine. These points, so long as the machine is in action, will give off streams of electricity, and as the particles of air repel the points by which they are electrified, the little machine will turn round rapidly, in the direction contrary to that of the stream of electricity. Perhaps, also, the reaction of the atmosphere against the current of air given off by the points, assists in giving it motion.

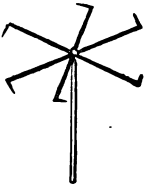


Fig. 263.

810. "When one part or side of an electric is positively, the other part or side is negatively electrified. Thus, if a plate of glass be positively electrified on one side, it will be negatively electrified on the other, and if the inside of a glass vessel be positive, the outside will be negative."

811. *Effects of electricity upon the magnet.*—The science of *electro-magnetism* dates from the discovery of Oersted, in 1819. 1. On connecting the poles of a powerful galvanic battery by a *uniting wire*, and placing a freely-suspended magnetic needle, horizontally and in a parallel direction, *beneath* the wire, he found that the needle immediately changed its position. The *law* of its motion was thus stated: "That end of the needle which is situated next to the negative side of the battery, or towards which the current of positive electricity is flowing, immediately moves to the westward." 2. On placing the needle *above* the wire, the same end of the needle moves to the east. Hence the following *formula* was stated: "*The* pole *above* which the *negative* electricity enters, is turned to the *west; under* which, to the *east.*" The *extent* of the declination caused by a voltaic circle depends upon its power, and the distance of the connecting wire from the needle; with a powerful battery, and at a small distance, it amounts to an angle of 45°. 3. When the uniting wire is placed in the same horizontal plane as the needle, no declinations to the east or west take place; but the pole of the needle next to the negative end of the wire is depressed when

the wire is placed on the west side of it, and elevated when the wire is on the east side. 4. When the uniting wire is placed at right angles to the needle, either above or below it, the latter remains at rest, unless the wire is brought close to one of its poles, in which case the pole is elevated when the negative end of the wire is at the west of the needle, and depressed when it is at the east. 5. Lastly, the uniting wire may be placed in a vertical direction, the needle remaining horizontal: when, with its upper extremity negative, it is placed exactly between the magnetic poles, no effect is produced; on moving it nearly midway towards either pole, the needle is attracted; on bringing it close to either pole, the needle is repelled; when the upper extremity of the wire is positive, the phenomena are reversed. These effects of the uniting wire take place through plates of glass, metal, stone, wood, resin, earthenware, or water.—Iron is rendered immediately magnetic by passing electricity from a galvanic battery through a copper wire wound round it. If a piece of iron, round which a copper wire, covered with silk thread, has been coiled, be made to touch the poles of a horse-shoe magnet, the copper wire is found to be electrically excited at the moment when the contact is made, and is capable of producing a spark at the instant when its extremities are connected together. These are the *leading facts* of the science; the subject will be treated in further detail and illustrated in the following chapter on *magnetism*.

812. *Chemical effects of electricity.*—The electricity produced by the electrical machine is generally allowed to be identical with that produced by the galvanic pile; their chemical effects are, however, remarkably different, and this is explained by comparing the *quantities* of electricity produced by each. An electric battery of fifteen jars, each containing 234 square inches of glass coated on each side, and charged by thirty turns of a powerful plate electrical machine, fifty inches in diameter, yields no more electricity than a platina and zinc wire, each 1-18th of an inch in diameter, placed 5-8ths of an inch deep in a diluted acid composed of one drop of sulphuric acid and four ounces of water, during three seconds. Again, the quantity of electricity associated with the elements of bodies in their various chemical combinations is so great, that, while electricity sufficient to decompose a grain of water can be easily procured during the chemical action of a few grains of zinc on a diluted acid, Mr

Faraday has inferred that no fewer than 800,000 charges of the electric battery just mentioned would be necessary to produce the same effect.

813. The *chemical effects* of the voltaic battery were first exhibited by Messrs Nicholson and Carlisle, in the *decompositions* which it produces. On immersing the wires into a cup of water, without contact with each other, the water is decomposed, its hydrogen is separated at the negative, its oxygen at the positive, pole. By wires of gold or platinum, the oxygen is obtained pure; with those of the more oxidable metals, it combines, and is converted into an oxide. Various substances are capable of being decomposed by the same agent, and it has been found that the *alkalies* are always separated at the *negative*, the *acids* at the *positive* pole, or extremity of the wire. Davy found that oxygen and hydrogen were separately disengaged from two glasses of water, even when communicating together by vegetable or animal substances. He then operated upon other compounds, and found that sulphur and metallic substances appeared at the negative pole, and oxygen and nitrogen at the positive pole, although the bodies containing them were separate from each other. Under the influence of electricity, an element may have its ordinary power of combination suspended, and be passed through bodies for which it has an affinity, without combining with them. Thus, acids were found capable of being *transferred* through alkaline solutions, and alkalies through acid solutions, to their respective poles. Davy also succeeded in decomposing potash and soda, proving that the two fixed alkalies are metallic oxides. He then analysed the earths, and obtained the four metals, barium, strontium, calcium, and magnesium, from the earths in which they are found. It was afterwards found that all the bases of the earths, except silica, are metallic, and capable of combining with iron.

814. It appears that different bodies have a peculiar relation to electricity, so that, when separated from their combinations with other bodies, they are attracted to the positive or to the negative pole of the battery. Hence, bodies have been distinguished by Berzelius into *electro-negatives*, or those which pass to the positive pole, and *electro-positives*, or those which pass to the negative pole. These terms denote that, during decomposition, bodies exhibit a different electric condition from that of the pole at which they appear.

The following table presents the elementary substances, as they are affected in this respect:—

Electro-Negatives.

Oxygen
Sulphur
Nitrogen
Chlorine
Iodine
Fluorine
Phosphorus
Selenium
Arsenic
Chromium
Molybdenum
Tungsten
Boron
Carbon
Antimony
Tellurium
Columbium
Titanium
Silicium
Osmium
Hydrogen

Electro-Positives.

Potassium
Sodium
Lithium
Barium
Strontium
Calcium
Magnesium
Glucinium
Yttrium
Aluminium
Zirconium
Manganese
Zinc
Cadmium
Iron
Nickel
Cobalt
Cerium
Lead
Tin
Bismuth
Uranium
Copper
Silver
Mercury
Palladium
Platinum
Rhodium
Iridium
Gold

When a compound, consisting of two bodies arranged in the same list, is decomposed, its elements are found to be electro-positive or electro-negative in regard to each other. Thus oxygen is always separated from any substance in the same list, at the positive pole; potassium, from any substance in the same list, at the negative pole. Oxygen is the most electro-negative, potassium the most electro-positive, of all known bodies.

815. The electric current formed by the *contact* of two metals, *increases*, in one of them, the tendency to affinity for some element of the solution, and *decreases* proportionably that tendency in the other. Upon this principle was founded Davy's attempt to preserve the copper sheathing of ships. "My results," he observes, "are of the most beautiful and unequivocal kind; a mass of tin renders a surface of copper, 200 or 300 times its own size, sufficiently electrical to have no action on sea-water." He found that cast iron was the best metal for protecting the copper, and that when the surface of the former was from 1-20th to 1-110th part of the surface of the latter, the copper underwent no corrosion; with small

protectors from 1-200th to 1-400th of the copper surface, the loss of copper increased as the protectors diminished; and when the protectors were only 1-1000th of the copper surface, a certain proportion of the copper was still preserved. A piece of zinc of the size of a pea was found sufficient to protect 40 or 50 square inches of copper, in whatever part of the latter surface it was situated. It was discovered, however, that the protection of the copper sheathing was accompanied by adhesion of sea-weeds and shell-fish, by chemical changes in the protectors, and foul depositions on the copper. It is stated that "the iron protectors in the *Glasgow* were converted into a substance like plumbago, which could be cut by a knife. A portion of this, wrapped in paper, was placed by a shipwright in his pocket for examination; the new substance at first became warm, but it soon grew hot, and in a short time passed into a state of absolute ignition by the action of the air." It therefore remained to be proved to what *extent* the copper should be protected in order to secure the desired effect. This plan was abandoned in 1828.

816. "Mr Faraday has lately introduced some new terms explanatory of his views of electro-chemical decomposition. He considers that what are called the *poles* of a voltaic battery possess no attractive or repulsive powers, but merely furnish a passage to the electrical current. He therefore employs the synonymous term *electrodes* (from ἤλεκτρον, and ὁδός, a way). The electric currents are supposed to circulate round the earth in a direction from east to west; hence, if a body to be decomposed be similarly placed, the point or surface at which positive electricity *enters*, is termed the *anode* (from ἀνα, upwards); the point or surface out of which it *passes*, is called the *cathode* (from κατὰ, downwards). Substances directly decomposable by electricity, are called *electrolytes* (from ἤλεκτρον, and λύω, to set free); their decomposition is therefore termed electrolyzation. The elements of an electrolyzed body are called *ions* (from ἰὼν, going); that which appears at the anode, commonly called the electro-negative element, is termed *anion;* that which appears at the cathode, or electro-positive element, *cation*. Thus, if water be electrolyzed, oxygen and hydrogen are ions—the former an anion, the latter a cation.

817. *Effects of electricity on animals.*—Electricity of great intensity, as that of lightning, produces immediate death. When applied in small quantity, it is found useful in diseases

of a paralytic kind, and in cases of suspended animation. The part of the body to which the stimulus is to be applied, must form part of the circuit through which the electricity passes; the connexion is effected by means of metallic rods, brass chains, and the common discharger. Some fishes have the power of giving electric shocks, the effects of which are the same as those procured by the friction of an electric. The Torpedo, when touched with both hands at the same time, one on the upper, the other on the lower surface, gives a shock like that of the Leyden jar, the two surfaces of the fish being in the same condition as the inner and outer coatings of the jar. The gymnotus electricus, or electrical eel, possesses the electrical powers of the torpedo in a higher degree; when small fish are placed in water with this animal, they are generally stunned, and sometimes killed, by the shock it is capable of imparting. The strongest shock of the gymnotus will pass for a short distance through the air, or across the surface of an electric, from one conductor to another, and then there can be perceived a small, but vivid spark of electrical fire, particularly if the experiment be made in the dark.

QUESTIONS ON CHAP. X.

770. In what form does electricity exhibit its most intense activity? On what do its phenomena, in their most general expression, depend? What is meant by electrical equilibrium? What are the results when the equilibrium is disturbed? What, when it is restored? What are the phenomena attending the communication of electricity?—771. Define the term electricity. How was this force discovered? What is an electric? What are the principal electrics? Explain the phenomena of alternate attraction and repulsion.—772. What is an electroscope? Explain the use of this instrument, with reference to Fig. 248. Under what circumstances do attractions and repulsions take place between two electrified bodies?—773. How many theories are there of electricity?—774. Explain Franklin's theory. State the difference between positive and negative electricity. What is the consequence when a positive and a negative body are connected by a conductor?—775. Explain the theory of Du Fay. What is meant by vitreous, and what by resinous electricity? When two balls are electrified, one with glass, and the other with wax, will they attract or repel each other?

776. What is meant by the conducting power of a body? Which are the best conductors? How is the conducting power of bodies employed in the protection of buildings from the effects of lightning? Which are the principal non-conductors? What relation subsists between electrics and non-electrics, conductors and non-conductors?—777. By what circumstances is the conducting power of bodies influenced? Illustrate the effect of temperature in this respect. Illustrate the effect produced by change of form.—778. What is the electric circuit? When is it said to be broken? Is electricity distributed through the substance, or over the surface of bodies? Do pointed or spherical bodies convey away electricity the more readily? How is this principle applied in the protection of buildings from lightning? When is a body said to be insulated?

779. In excitation by friction, how does the nature of the rubber influence the result? Illustrate this influence from the tabular sketch.—780. What are the several parts of an electrical machine? What is the use of the pointed wires in the prime conductor? How is it accounted for that a mere surface of metal will contain as much electric fluid as if it were solid?—781. When a piece of glass, or sealing-wax, is excited by rubbing it with the hand or a piece of silk, whence is the electricity derived? When the cushion is insulated, why is there a limited quantity of electric matter to be obtained from it? What is then necessary that more electric matter may be obtained from the cushion?—782. If an insulated person take the chain, connected with the cushion, in his hand, what change will be produced in his natural quantity of electricity? If the insulated person take hold of the chain connected with the prime conductor, and the machine be worked, what then will be the change produced in his electrical state?—783. If two insulated persons take hold of the two chains, one connected with the prime conductor, and the other with the cushion, what changes will be produced? If they both take hold of the chain, what will be the effect?—784. Explain the reason why the little images dance between the two metallic plates, Fig. 250.—785. Explain Fig. 251. Does it make any difference in respect to the motion of the images, or of the ball between the bells, whether the electricity be positive or negative? When a person is highly electrified, why does he exhibit an appearance of the utmost terror?

786. Give an instance of the excitation of electricity by change of temperature.—787. Illustrate the excitation of electricity by change of form.—788. Show how the effects produced by the electrical machine are connected with chemical action.

Illustrate the phenomenon of electrical excitement, as produced by combustion.—789. What kind of bodies exhibit electrical excitement by contact? What opinions have been maintained on this subject?—790. What is meant by induced electricity? Explain this phenomenon by reference to Fig. 252.

791. What part of the electrical apparatus is constructed on the principle of induced electricity? How is the Leyden vial constructed? Why is not the whole surface of the vial covered with the tin-foil? How is the Leyden vial charged? In what manner may a number of these vials be charged? What is an electrical battery?—792. Explain the design of Fig. 254, and show how an equilibrium is produced by the discharging rod. When it is desired to pass the electrical fluid through any substance, where must it be placed in respect to the two sides of the battery?—793. Suppose the battery is charged, what must a person do to take the shock? What circumstance is related which shows the surprising velocity with which electricity is transmitted?—794. Is the electricity of the atmosphere positive or negative? At what times does the atmosphere contain most electricity? How are the different electrical states of the atmosphere ascertained?

795. What is meant by intensity of electricity? What is an electrometer? Explain the principle of the quadrant electrometer, by reference to Fig. 255. Explain the use of the gold leaf electrometer.—796. Who first discovered that electricity and lightning are the same? What phenomena are mentioned which belong in common to electricity and lightning?—797. How may buildings be protected from the effects of lightning? Which is the best conductor, iron or copper? What circumstances are necessary, that the rod may be relied on as a protector? Is copper or iron the better material for conductors of this kind?

798. How was galvanism discovered? Why was it afterwards termed voltaism? Explain the Fig. 257, and give the designation of such an arrangement.—799. Explain the Fig. 258, and show the coincidence between this and the preceding operation. —800. What is a compound voltaic pile or circle? What is its power?—801. Describe the trough battery, Fig. 260, and state under what circumstances it is employed.—802. What are the liquids usually employed in the trough battery?—803. How did Wollaston explain the phenomena of the voltaic pile?—804. Explain the electro-chemical theory of Davy.

805. When the electric fluid passes along a perfect conductor, is its passage attended by heat and light? Why are sparks produced by a voltaic battery when the contact of the wires is broken? How may the evolution of heat be detected, on unit-

ing the poles of a battery? On what do the heating effects of voltaic electricity depend? In what ratio is the heat developed? How is this illustrated?—806. Describe the experiment, Fig. 262, and state the principle which it illustrates.—807. What is the appearance of electrical light, as seen through a prism? —808. What is said concerning the different colours of electrical light, when passing between surfaces of different kinds?—809. Describe Fig. 263, and explain the principle on which its motion depends.—810. Suppose one part or side of an electric is positive, what will be the electrical state of the other side or part?

811. Under what circumstances does the magnetic needle change its position? State the law of its motion. If the needle be placed above the uniting wire, how does it move? State the formula. What is the extent of declination, with a powerful battery, and at a small distance? When the uniting wire is placed in the same horizontal plane as the needle, what results ensue? When it is placed at right angles to the needle, what are the results? When placed in a vertical direction, the needle being horizontal, what effects may be produced?

812. Is there any difference in the chemical effects of electricity, as produced by the electrical machine and by a voltaic battery? On what does the difference depend? Give a general idea of the comparative quantities of electricity developed by these two machines. State also the comparative energies of these machines required for the decomposition of a grain of water.—813. In the decomposition of water by a voltaic battery, at which pole does each of its elements appear? At which pole do acids and alkalies respectively appear? Give instances in which an element, under the influence of electricity, may have its ordinary power of combination suspended.—814. Explain the difference between an electro-negative and an electro-positive. What do these terms denote? Which is the most electro-negative, and which the most electro-positive, of all known bodies?

815. Explain the principle on which Davy founded his attempt to preserve the copper sheathing of ships. What quantity of tin renders a given surface of copper sufficiently electrical to have no action on sea-water? What difficulties occurred in the prosecution of this object?—816. What is an electrode? Why was the term introduced? What is an anode, and a cathode? What is an electrolyte? Explain the terms ion, anion, and cation. If water be electrolyzed, what are its elements called, according to this nomenclature?—817. What are the effects of electricity on animals? In what cases of disease has its application been found beneficial? What animals are endowed with electrical properties?

CHAP. XI.

OF MAGNETISM.

818. "The native *magnet*, or *loadstone*, is an ore of iron, which is found in various parts of the world. Its colour is iron black, its specific gravity from 4 to 5, and it is sometimes found in crystals. This substance, without any preparation, attracts iron and steel, and when suspended by a string, will turn one of its sides towards the north, and another towards the south. It appears that an examination of the properties of this species of iron ore, led to the important discovery of the *magnetic needle*, and subsequently laid the foundation of the science of magnetism, though at the present day magnets are made without this article.

819. "The whole science of *Magnetism* is founded on the fact that pieces of iron or steel, after being treated in a certain manner, and then suspended, will constantly turn one of their ends towards the north, and consequently the other towards the south. The same property has been more recently proved to belong to the metals *nickel* and *cobalt*, though with much less intensity.

820. "The *poles* of a magnet are those parts which possess the greatest power, or in which the magnetic virtue seems to be concentrated. One of the poles points north, and the other south. The *magnetic meridian* is a vertical circle in the heavens, which intersects the horizon at the points to which the magnetic needle, when at rest, directs itself. The *axis* of a magnet, is a right line which passes from one of its poles to the other. The *equator* of a magnet, is a line perpendicular to its axis, and is at the centre between the two poles.

821. "The leading properties of the magnet are the following. 1. It attracts iron and steel, and when suspended so as to move freely, it arranges itself so as to point north and south: this is called the *polarity* of the magnet. 2. When the *south* pole of one magnet is presented to the *north* pole of another, they will attract each other: this is called *magnetic attraction*. 3. But if the two north or two south poles be brought together, they will repel each other, and this is called *magnetic repulsion*. 4. When a magnet is left to move freely, it does not lie in a horizontal direction, but one pole

inclines downwards, and consequently the other is elevated above the line of the horizon. This is called the *dipping*, or *inclination* of the magnetic needle. Any magnet is capable of communicating its own properties to iron or steel, and this, again, will impart its magnetic virtue to another piece of steel, and so on indefinitely.

822. "If a piece of iron or steel be brought near one of the poles of a magnet, they will *attract* each other, and if suffered to come into contact, will adhere so as to require force to separate them. This attraction is mutual; for the iron attracts the magnet with the same force that the magnet attracts the iron. This may be proved, by placing the iron and magnet on pieces of wood floating on water, when they will be seen to approach each other mutually. The force of *magnetic attraction* varies with the distance in the same ratio as the force of gravity; the attracting force being inversely as the square of the distance between the magnet and the iron.

823. "The magnetic force is not sensibly affected by the interposition of any substance except those containing iron or steel. Thus, if two magnets, or a magnet and piece of iron, attract each other with a certain force, this force will be the same, if a piece of glass, wood, or paper, be placed between them. Neither will the force be altered, by placing the two attracting bodies under water, or in the exhausted receiver of an air-pump. This proves that the magnetic influence passes equally well through air, glass, wood, .paper, water, and a vacuum.

824. "Heat weakens the attractive power of the magnet, and a white heat entirely destroys it. Electricity will change the poles of the magnetic needle, and the explosion of a small quantity of gun-powder on one of the poles, will have the same effect. On the other hand, the attractive power of the magnet may be increased by permitting a piece of steel to adhere to it, and then suspending to the steel a little additional weight every day; for it will sustain, to a certain limit, a little more weight on one day than it would on the day before.

825. "Small natural magnets will sustain more than large ones in proportion to their weight. It is rare to find a natural magnet, weighing 20 or 30 grains, which will lift more than thirty or forty times its own weight. But a minute piece of natural magnet, worn by Sir Isaac Newton in a

ring, which weighed only three grains, is said to have been capable of lifting 746 grains, or nearly 250 times its own weight.

826. "The magnetic property may be communicated from the loadstone, or artificial magnet, in the following manner, it being understood that the north pole of one of the magnets employed, must always be drawn towards the south pole of the new magnet, and that the south pole of the other magnet employed, is to be drawn in the contrary direction. The north poles of magnetic bars are usually marked with a line across them, so as to distinguish this end from the other.

827. " Place two magnetic bars, A and B, Fig. 264, so that the north end of one may be nearest the south end of the other, and at such a distance that the ends of the steel bar to be touched may rest upon them. Having thus arranged them, as shown in the figure, take the two magnetic bars, D and E, and apply the south end of E, and the north end of D, to the middle of the bar C, elevating their ends as seen in the figure. Next separate the bars E and D, by drawing them in opposite directions along the surface of C, still preserving the elevation of their ends; then removing the bars D and E to the distance of a foot or more from the bar C, bring their north and south poles into contact, and then having again placed them on the middle of C, draw them in contrary directions, as before. The same process must be repeated many times on each side of the bar C, when it will be found to have acquired a strong and permanent magnetism.

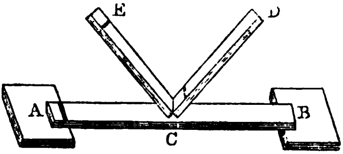


Fig. 264.

828. " If a bar of iron be placed, for a long period of time, in a north and south direction, or in a perpendicular position, it will often acquire a strong magnetic power. Old tongs, pokers, and fire-shovels, almost always possess more or less magnetic virtue, and the same is found to be the case with the iron window bars of ancient houses, whenever they have happened to be placed in the direction of the magnetic line.

829. " A *magnetic needle*, such as is employed in the mariner's and surveyor's compass, may be made by fixing a

piece of steel on a board, and then drawing two magnets from the centre towards each end, as directed at Fig. 264. Some magnetic needles in time lose their virtue, and require again to be magnetized. This may be done by placing the needle, still suspended on its pivot, between the opposite poles of two magnetic bars. While it is receiving the magnetism, it will be agitated, moving backwards and forwards, as though it were animated, but when it has become perfectly magnetized, it will remain quiescent.

830. "The *dip*, or *inclination* of the magnetic needle, is its deviation from its horizontal position, as already mentioned. A piece of steel, or a needle, which will rest on its centre, in a direction parallel to the horizon, before it is magnetized, will afterwards incline one of its ends towards the earth. This property of the magnetic needle was discovered by a compass maker, who, having finished his needles before they were magnetized, found that immediately afterwards, their north ends inclined towards the earth, so that he was obliged to add small weights to their south poles, in order to make them balance, as before.

831. "The dip of the magnetic needle is measured by a graduated circle, placed in the vertical position, with the needle suspended by its side. Its inclination from a horizontal line marked across the face of this circle, is the measure of its dip. The circle, as usual, is divided into 360 degrees, and these into minutes and seconds. The dip of the needle does not vary materially at the same place, but differs in different latitudes, increasing as it is carried towards the north, and diminishing as it is carried towards the south. At London, the dip for many years has varied little from 72 degrees. In the latitude of 80 degrees north, the dip, according to the observations of Captain Parry, was 88 degrees.

832. "Although, in general terms, the magnetic needle is said to point north and south, yet this is very seldom strictly true, there being a variation in its direction, which differs in degree at different times and places. This is called the *variation*, or *declination*, of the magnetic needle. This variation is determined at sea, by observing the different points of the compass at which the sun rises, or sets, and comparing them with the true points of the sun's rising or setting, according to astronomical tables. By such observations it has been ascertained that the magnetic needle is continually declining alternately to the east or west from due north, and

that this variation differs in different parts of the world at the same time, and at the same place at different times.

833. "In 1580, the needle at London pointed 11 degrees 15 minutes east of north, and in 1657 it pointed due north and south, so that it moved during that time at the mean rate of about 9 minutes of a degree in each year, towards the north. Since 1657, according to observations made in England, it has declined gradually towards the west, so that in 1803, its variation west of north was 24 degrees. At Hartford, Connecticut, in latitude about 41°, it appears from a record of its variations, that since the year 1824, the magnetic needle has been declining towards the west, at the mean rate of 3 minutes of a degree annually, and that on the 20th of July, 1829, the variation was 6 degrees 3 minutes west of the true meridian. The cause of this annual variation has not been demonstrated, though, according to the experiments of Mr Canton, it has been ascertained that there are slight variations during the different months of the year, which seem to depend on the degrees of heat and cold.

ELECTRO-MAGNETISM.

834. "Long before the discovery of galvanism, it was suspected that there existed an affinity or connection between magnetism and electricity. In the year 1774, one of the philosophical societies of Germany proposed as the subject of a prize dissertation, the question, 'Is there a real and physical analogy between the electric and magnetic forces?' The question was then answered in the negative; but the existence of such an analogy was from time to time affirmed by various philosophers.

835. "The *aurora borealis*, which has long been supposed to be an electrical phenomenon, was observed to influence the magnetic needle; and lightning, well known to be nothing more than an electrical movement, was known in many instances to have destroyed or reversed the polarity of the compass. An instance of this kind, which might have led to very disastrous consequences, is related of a ship in the midst of the Atlantic, which being struck with lightning, had the polarity of all her compasses reversed. This being unknown, the ship was directed as usual by the compass, until the ensuing evening, when the stars showed that her direction was in the exactly opposite course from what was intended, and

then it was that the phenomenon in question was first suspected. These discoveries of course led philosophers to try the effects of powerful electrical batteries on pieces of steel, and although polarity was often induced in this manner, yet the results were far from being uniform, and the experiments on this subject seem in a measure to have ceased, when the discovery of the galvanic influence opened a new field of inquiry, and gave an unusual impulse to the labours, investigations, and experiments of philosophers throughout Europe.

836. "It was, however, more than twenty years from the time of Galvani's discovery, before the science of electro-magnetism was developed, the first having taken place in 1791, while the experiments of Oersted, the real discoverer of electro-magnetism, were made in 1819. Oersted was professor of natural philosophy, and secretary to the Royal Society of Copenhagen His experiments, and others on the subject in question, are detailed at considerable length, and illustrated by many drawings, but we shall here only give such an abstract as will make the subject intelligible.

837. "The two poles of the battery, Fig. 265, are connected by means of a copper wire of a yard or two in length, the two parts being supported on a table in a north and south direction, for some of the experiments, but in others the direction must be changed, as will be seen. This wire, it will be remembered, is called the *uniting wire.* The apparatus being thus prepared, and the galvanic battery in action, take a magnetic needle six or eight inches long, properly balanced on its pivot, and, having detached the wire from one of the poles, place the magnetic needle under the wire, but parallel with it, and having waited a moment for the vibrations to cease, attach the uniting wire to the pole. The instant this is done, and the galvanic circuit completed, the needle will deviate from its north and south position, turning towards the east or west, according to the direction in which the galvanic current flows. If the current flows from the north, or the end of the wire along which it passes to the south is connected with the positive side of the battery, then the north pole of the needle will turn towards the east; but if the direction of the current is changed, the same pole will turn in the opposite direction. If the uniting wire is placed *under* the needle, instead of over it, as in the above experiment, the contrary effect will be produced, and the north pole will deviate towards the west,

838. "These deviations will be understood by the following figures. In Fig. 265, N presents the north, and S the south pole of the magnetic needle, and *p* the positive and *n* the negative ends of the uniting wire. The galvanic current, therefore, flows from *p* towards *n*, or, the wire being parallel with the needle, from the north towards the south, as shown by the direction of the arrow in the figure. Now the uniting wire being *above* the needle, the pole N, which is towards the positive side of the battery, will deviate towards the east, and the needle will assume the direction N′ S′.

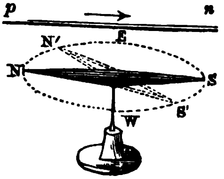


Fig. 265.

839. "On the contrary, when the uniting wire is carried *below* the needle, the galvanic current being in the same direction as before, as shown by Fig. 266, then the same, or north pole, will deviate towards the west, or in the contrary direction from the former, and the needle will assume the position N S′. When the uniting wire is situated in the same horizontal plane with the needle, and is parallel to it, no movement takes place towards the east or west; but the needle dips, or the end towards the positive end of the wire is depressed, when the wire is on the east side, and elevated when it is on the west side.

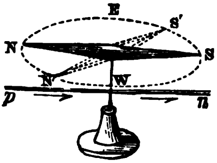


Fig. 266.

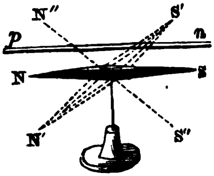


Fig. 267.

840. "Thus, if the uniting wire *p n*, Fig. 267, is placed on the east side of the needle N S, and parallel to, and on a level with it, then the north pole, N, being towards the positive end of the wire, will be elevated, and the needle will assume the position of the dotted needle N′ S′. But if the wire be changed to the western side, other circumstances being the same, then the north pole will be depressed, and the needle will take the direction of the dotted line N″ S″.

841. "If the uniting wire, instead of being parallel to the

needle, be placed at right angles with it, that is, in the direction of east and west, and the needle brought near, whether above or below the wire, then the pole is depressed when the positive current is from the west, and elevated when it is from the east. Thus, the pole s, Fig. 268, is elevated, the current of positive electricity being from *p* to *n*, that is, across the needle from the east towards the west. If the direction of the positive current is changed, and made to flow from *n* to *p*, the other circumstances being the same, the south pole of the needle will be depressed.

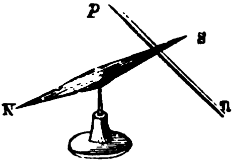


Fig. 268.

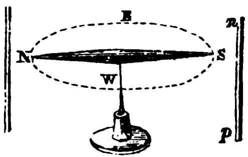


Fig. 269.

842. "When the uniting wire, instead of being placed in a horizontal position, as in the last experiment, is placed vertically, either to the north or south of the needle, and near its pole, as shown by Fig. 269, then if the lower extremity of the wire receives the positive current, as from *p* to *n*, the needle will turn its pole towards the west. If now the wire be made to cross the needle at a point about halfway between the pole and the middle, the same pole will deviate towards the east. If the positive current be made to flow from the upper end of the wire, all these phenomena will be reversed.

LAWS OF ELECTRO-MAGNETIC ACTION.

843. "An examination of the facts which may be drawn from an attentive consideration of the above experiments, is sufficient to show that the magnetic force which emanates from the conducting wire, is different in its operation from any other force in nature, with which philosophers had been acquainted. This force does not act in a direction parallel to that of the current which passes along the wire, 'but its action produces motion in a circular direction *around* the wire, that is, in a direction at right angles to the radius, or in the direction of the tangent to a circle described round the wire in a plane perpendicular to it.'

844. " In consequence of this circular current, which seems to emanate from the regular polar currents of the battery, the magnetic needle is made to assume the positions indicated by the figures above described, and the effect of this is, to change the direction of the needle from the magnetic meridian, moving it through the section of a circle in a direction depending on the relative position of the wire and the course of the electric fluid. And we shall see hereafter that there is a variety of methods by which this force can be applied to produce a continued circular motion.

CIRCULAR MOTION OF THE ELECTRO-MAGNETIC FLUID.

845. We have already stated that the action of this fluid produces motion in a *circular* direction. Thus, if we suppose the conducting wire to be placed in a vertical situation, as shown by Fig 270, and *p n*, the current of positive electricity, to be descending through it, from *p* to *n;* and if through the point *c* in the wire the plane N N be taken, perpendicular to *p n*, that is in the present case a horizontal plane; then if any number of circles be described in that plane, having *c* for their common centre, the action of the current in the wire upon the north pole of the magnet will be to move it in a direction corresponding to the motion of the hands of a watch, having the dial towards the positive pole of the battery. The arrows show the direction of the current's motion in the figure. When the direction of the electrical current is reversed, the wire still having its vertical position, the direction of the circular action is also reversed, and the motion is that of the hands of the watch moving backwards.

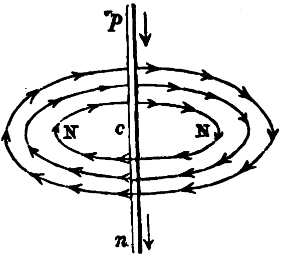


Fig. 270.

846. " As the magnetic needle cannot perform entire revolutions when it is crossed by the conducting wire, it becomes necessary, in order to show clearly that such a circulation as we have supposed actually exists, to describe more clearly than we have yet done, the means of demonstrating such an action, and the corresponding motion. Now the metals being conductors of the electric fluid, if we employ one through the

substance of which the magnetic needle can move, we shall have an opportunity of knowing whether the fluid has the circular action in question, for, then the needle will have liberty to move in the direction of the electrical current. For this purpose *mercury* is well adapted, being a good conductor of electricity, and at the same time so fluid as to allow a solid to circulate in it, or on its surface, with considerable facility. This, therefore, is the substance employed in these experiments.

MEANS OF PRODUCING ELECTRO-MAGNETIC ROTATIONS.

847. "The continued revolution of one of the poles of a magnet round a vertical conducting wire, may be produced in the following manner:—The small glass cup, Fig. 271, of which the right hand cut is a section, is pierced at the bottom for the admission of the crooked piece of copper wire D, which is made to communicate with one of the poles of a galvanic battery. To the end of this wire, which projects within the cup, is attached, by means of a fine thread, the end of the magnet A. The string must be of such length as to allow the upper end of the magnet to reach nearly the top of the cup. The vertical wire C is the positive pole of the battery.

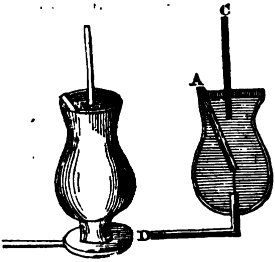


Fig. 271.

848. "Having made these preparations, fill the cup so full of mercury as only to allow a small portion of the upper end of the magnet to float above the surface, as shown in the figure. Then, by means of a little frame, or otherwise, fix the copper wire of the positive pole in the centre of the mercury, letting it dip a little below the surface, and on connecting the negative pole with the wire D, the magnet will revolve round the copper wire, and continue to do so as long as the connection between the two poles of the battery and the mercury remains unbroken. To insure close contact between the poles of the battery and the mercury, the ends of the wires where they dip into the mercury are amalgamated, which is done by means of a little nitrate of mercury, or by rubbing them, being of copper, with the metal itself.

REVOLUTION OF THE CONDUCTING WIRE ROUND THE POLE OF THE MAGNET.

849. "In the above example the wire is *fixed*, while the electrical current gives motion to the magnet. But this order may be reversed, and the wire made to *revolve*, while the magnet is stationary. The apparatus for this purpose is represented by Fig. 272, and consists of a shallow glass cup, with a tubular stem to hold the mercury. In the stem, as seen in the section on the right, there is a small copper socket, which is fixed there by being fastened to a copper plate below, which plate is cemented to the glass so that no mercury can escape. This plate is tinned and amalgamated on the under side, and stands on another plate, the upper side of which is also tinned and amalgamated, and between these the conducting wire passes, so as to insure a perfect metallic continuity between the poles of the battery. A strong cylindrical magnet is placed in the copper socket, with its upper end so high as to reach a little above the mercury when the cup is filled. The wire connected with the pole of the battery, which dips into the mercury, is suspended by means of loops, as seen in the figures. When the apparatus is thus arranged, and a communication made through it, between the poles of the battery, the wire will revolve round the magnet with great rapidity.

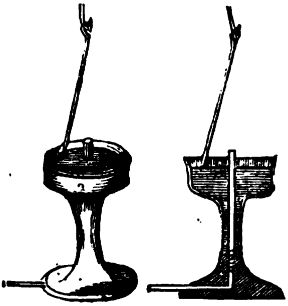


Fig. 272.

850. "A more simple apparatus, answering a similar purpose, and in which the wire revolves very rapidly, with a very small voltaic power, is represented by Fig. 273. It consists of a piece of glass tube, G G, the lower end of which is closed by a cork, through which a small piece of soft iron

wire, M, is passed, so as to project above and below. A little mercury is then poured in so as to make a channel between the wire and the glass tube. The upper orifice of the tube is also closed by a cork, through which a piece of copper wire, D, passes, and terminates in a loop. Another piece of wire, C, is suspended from this by a loop, the end of which dips into the mercury, and is amalgamated. In this arrangement, a temporary magnet is formed of the soft iron wire, M A, by the electrical fluid, and around this the moveable wire, C, revolves rapidly, changing its direction, as usual, when the direction of the current is changed.

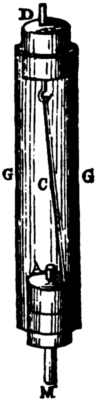


Fig. 273.

REVOLUTION OF A MAGNET ROUND ITS OWN AXIS.

851. "After it was found that a conducting wire might be made to revolve round a magnet, and a magnet round a conducting wire, many attempts were made to obtain the rotation of a magnet and of a conductor around their own axes. The rotation of a magnet on its axis may be accomplished by means of galvanism, by the following method:—

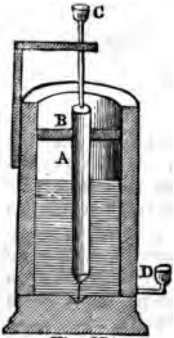


Fig. 274.

852. "The cylindrical magnet, A, Fig. 274, terminates at its lower extremity in a sharp point, which rests in a conical cavity of agate, so as much as possible to avoid friction. The vessel, the section of which is here shown, may be of glass or wood. The upper end of the magnet is supported in the perpendicular position by a thin slip of wood, passing across the upper part of the vessèl, and having an aperture through it, of proper size. A piece of quill is fitted on the upper end of the magnet, and rising a little above it, forms a cup to hold a globule of mercury. Into this mercury is inserted the lower end of the wire C, which has a cup on the top, containing mercury for the usual purpose. The end of the wire C must be amalgamated, as also the termination of the poles of the battery, which dip into the cups C and D. A copper wire of considerable size pierces the bottom of the vessel, and ends in the cup D, like the

other, containing mercury, in order to make the contact perfect. The vessel being now filled with mercury nearly up to A, so as to cover about one-half the magnet, and the ends of the galvanic poles inserted into the cups C and D, the magnet begins to revolve, and continues to do so as long as the connection is unbroken.

853. "In order to produce the rotation of a magnet, it is necessary that the electrical influence, in every instance, should act only on one of the poles at the same time, because the directions of the current on the two ends are contrary to each other, and therefore the two forces would be neutralized, and no motion be produced. In the above experiment, the electrical current, having passed the upper half of the magnet, is diffused in the mercury in which the lower half is buried, and thus produces no sensible effect upon it.

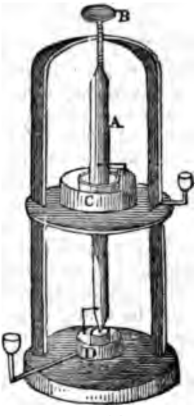


Fig. 275.

854. "Another method of producing the rotation of a magnet, is represented by Fig. 275. In this, A is a cylindrical magnet pointed at both ends, and running in an agate cup, which is fixed on a stem rising from the bottom of the stand. Its upper point runs in a little cavity in the end of the thumb-screw B, which passes through the cap of the framework of the apparatus. Near the middle of the magnet, this frame, which is of wood, supports a shelf, on which rests the circular cistern of mercury, C, the magnet passing freely through the centre of both. A cistern of mercury, D, also surrounds the lower point of the magnet, and in the centre of this is placed the agate cup. A piece of copper wire, projecting into the interior of these cisterns, terminates in a cup holding mercury, for the purpose of effecting a communication with the galvanic battery, in the usual manner. A small wire of copper, pointed, and amalgamated at the lower end, is fastened to the magnet, and made to dip into each of the cisterns of mercury, as seen in the figure.

855. "In this arrangement, the lower half of the magnet

only forms a part of the galvanic circle, the fluid passing in at one cup and out at the other by the following routine, which is apparent by the figure. Suppose the positive wire is placed in the upper cup, then the circuit will be from the cup along the wire to the mercury in the cistern, and from the mercury through the bent wire to the magnet—down the magnet through the lower bent wire to the mercury, and thence to the cup, and the negative pole of the battery. When the galvanic current is thus established, the rotation of the magnet begins, and if the points of the axis are delicate, and the friction small, it will revolve rapidly.

VIBRATORY AND ROTATORY MOTIONS PRODUCED BY MEANS OF HORSE-SHOE MAGNETS.

856. "By the use of these magnets, both the magnetic poles conspire to give the motion. The influence of the two poles being in contrary directions, and so near each other that the wire or wheel placed between them is within the magnetic currents of both, the effect appears to be, to form a current at right angles to the vibrating wire. The wire becomes magnetic, by the galvanic power, every time it touches the mercury between the poles of the magnet, and consequently is thrown backwards or forwards by the magnetic current, according to its direction; hence, if the poles of the battery are charged so as to carry the electricity in a contrary direction through the apparatus, the impulse on the wire or wheel will also be changed to the opposite direction. If the poles of the magnet be changed, by turning it over, the same effect will be produced, and the wheel will revolve in a contrary direction from what it did before.

857. "Thus, if the magnet be laid in the direction of north and south, with the poles towards the north, the north pole being on the east side, and the positive electricity be sent through the vibrating wire, upwards, then the vibrating force will be towards the north; but if either the poles of the magnet or those of the battery be changed, the wire will be thrown towards the south.

VIBRATION OF A WIRE.

858. "A conducting copper wire, w, Fig. 276, is suspended by a loop from a hook of the same metal, which passes through *an arm* of metal or wood, as seen in the cut. The upper

end of the hook terminates in the cup P, to contain mercury. The lower end of the copper wire just touches the mercury, Q, contained in a little trough about an inch long, formed in the wood on which the horse-shoe magnet, M, is laid, the mercury being equally distant from the two poles. The cup, N, has a stem of wire, which passes through the wood of the platform into the mercury, this end of the wire being tinned, or amalgamated, so as to form a perfect contact.

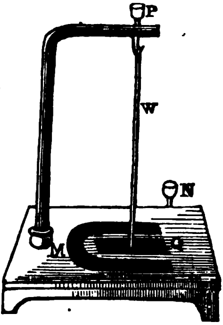


Fig. 276.

859. "Having thus prepared the apparatus, put a little mercury into the cups P and N, and then form the galvanic circuit by placing the poles of the battery in the two cups, and if every thing is as it should be, the wire will begin to vibrate, being thrown with considerable force either towards M or Q, according to the position of the magnetic poles, or the direction of the current, as already explained. In either case it is thrown out of the mercury, and the galvanic circuit being thus broken, the effect ceases until the wire falls back again by its own weight, and touches the mercury, when the current being again perfected, the same influence is repeated, and the wire is again thrown away from the mercury, and thus the vibratory motion becomes constant. This forms an easy and beautiful electro-magnetic experiment, and may be made by any one of common ingenuity, who possesses a galvanic battery, even of small power, and a good horse-shoe magnet.

860. "The platform may be nothing more than a piece of pine board eight inches long and six wide, with two sticks of the same wood, forming a standard and arm for suspending the vibrating wire. The cups may be made of percussion caps, exploded, and soldered to the ends of pieces of copper bell wire. The wire must be nicely adjusted with respect to the mercury, for if it strikes too deep, or is too far from the surface, no vibrations will take place. It ought to come so near the mercury as to produce a spark of electrical fire, as it passes the surface, at every vibration, in which case it may be known that the whole apparatus is well arranged. The

vibrating wire must be pointed and amalgamated, and may be of any length, from a few inches to a foot or two.

ROTATION OF A WHEEL.

861. "The same force which throws the wire away from the mercury, will cause the rotation of a spur-wheel. For this purpose the conducting wire, instead of being suspended as in the former experiment, must be fixed firmly to the arm, as shown by Fig. 277. A support for the axis of the wheel may be made by soldering a short piece to the side of the conducting wire, so as to make the form of a fork, the lower ends of which must be flattened with a hammer, and pierced with fine orifices, to receive the ends of the axis.

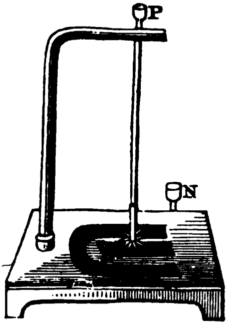


Fig. 277.

862. "The apparatus for a revolving wheel is in every respect like that already described for the vibrating wire, except in that above noticed. The wheel may be made of brass or copper, but must be thin and light, and so suspended as to move freely and easily. The points of the notches must be amalgamated, which is done in a few minutes, by placing the wheel on a flat surface, and rubbing them with mercury by means of a cork. A little diluted acid from the galvanic battery will facilitate the process. The wheel may be from half an inch to several inches in diameter. A cent hammered thin, which may be done by heating it two or three times during the process, and then made perfectly round, and its diameter cut into notches with a file, will answer every purpose.

863. "This affords a striking and novel experiment; for when every thing is properly adjusted, the wheel instantly begins to revolve by touching with one of the wires of the battery the mercury in the cup P or N. When the poles of the magnet, or those of the battery, are changed, the wheel instantly revolves in a contrary direction from what it did before. It is, however, not absolutely necessary to divide the wheel into notches, or rays, in order to make it revolve, though the motion is more rapid, and the experiment succeeds much better by doing so.

REVOLUTION OF TWO WHEELS.

864. "If two wheels be arranged as represented by Fig. 278, they will both revolve by the same electrical current. Each horse-shoe magnet has its trough of mercury. The magnets have been omitted in the drawing, but are to be placed precisely as in the last figure. The electrical communication is to be made through the cups of mercury, P and N, and its course is as follows:—From the cup it passes into the mercury; from the mercury through the radii to the axis of the wheel, and along the axis to the other wheel, down which it passes to the mercury, and so to the other cups, and to the opposite pole of the battery. The poles of the magnets for this experiment must be opposed to each other.

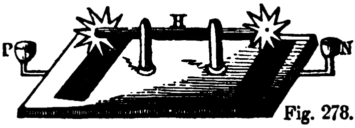


Fig. 278.

ELECTRO-MAGNETIC INDUCTION.

865. "Experiment proves that the passage of the galvanic current through a copper wire renders iron magnetic when in the vicinity of the current. This is called *magnetic induction.* The apparatus for this purpose is represented by Fig. 279, and consists of a copper wire coiled, by winding it around a piece of wood. The turns of the wire should be close together for actual experiment, they being parted in the figure to show the place of the iron to be magnetized. The best method is, to place the coiled wire, which is called an *electrical helix*, in a glass tube, the two ends of the wire of course projecting. Then placing the body to be magnetized within the folds, send the galvanic influence through the whole, by placing the poles of the battery in the cups.

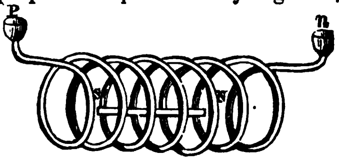


Fig. 279.

866. "Steel thus becomes permanently magnetic, the poles, however, changing as often as the fluid is sent through it in a contrary direction. A piece of watch-spring placed in the helix, and then suspended, will exhibit polarity, but if its position be reversed in the helix, and the

current again sent through it, the north pole will become south. If one blade of a knife be put into one end of the helix, it will repel the north pole of a magnetic needle, and attract the south; and if the other blade be placed in the opposite end of the helix, it will attract the north pole, and repel the south, of the needle.

867. "*Temporary magnets.*—Temporary magnets, of almost any power, may be made by winding a thick piece of soft iron with many coils of insulated copper wire. The best form of a magnet for this purpose is that of a horse-shoe, which may be made in a few minutes by heating and bending a piece of cylinder iron, an inch or two in diameter, into this form. The copper wire (bell wire) may be insulated by winding it with cotton thread. If this cannot be produced, common bonnet wire will do, though it makes less powerful magnets than copper.

868. "The coils of wire may begin near one pole of the magnet and terminate near the other, as represented by Fig. 280; or the wire may consist of shorter pieces wound over each other, on any part of the magnet. In either case, the ends of the wire, where several pieces are used, must be soldered to two strips of tinned sheet copper, for the combined positive and negative poles of the wires. To form the magnet, these pieces of copper are made to communicate with the poles of the battery, by means of cups containing mercury, as shown in the figure, or by any other method.

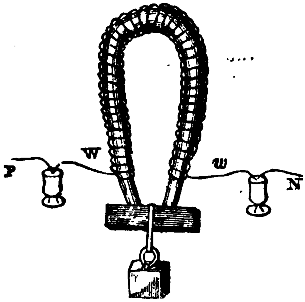


Fig. 280.

869. "The effect is surprising, for on completing the circuit with a piece of iron an inch in diameter, in the proper form, and properly wound, a man will find it difficult to pull off the armature from the poles; but on displacing one of the galvanic poles, the attraction ceases instantly, and the man, if not careful, will fall backwards, taking the armature with him. Magnets have been constructed in this manner, which would suspend two or three thousand pounds.

870. "GALVANIC BATTERY.—One of the most convenient

forms of a galvanic battery for the experiments above described, is represented by Fig. 281. It consists of two concentric cylinders, of sheet copper, soldered to the same bottom. The diameter of the outer cylinder may be six inches, that of the inner one four and a half inches. The height may be a foot or more. Between these cylinders of copper is placed one of zinc, but so as not to touch them nor the bottom. This is best done by tying three or four pieces of pine lengthwise to the zinc cylinder, letting them project half an inch below the bottom. By this arrangement the zinc can be taken from the acid, or plunged into it, at any moment. Another cylinder of zinc within the smaller one of copper may be added, to increase the power, when a single one is found insufficient. This must have a metallic connection with the other zinc cylinder.

871. "The cups P N are the positive and negative sides of the battery. The best way of forming this part of the apparatus is to solder a slip of tinned copper to the inside of the copper cylinder, and another to the zinc, as shown in the plate. The outer ends of these may readily be formed into cups by cutting the copper slip one-third in two on each side, then turning this part at right angles with the other, and rolling what were the outer edges together, and soldering them. Such a battery is ample for all the experiments we have described. A cheap and convenient liquid for the battery consists of water saturated with common salt, with a little sulphuric acid, say an ounce or two to a quart."

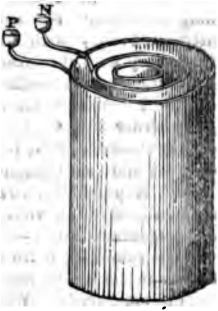


Fig. 281.

QUESTIONS ON CHAP. XI.

818. What is said of the suspicion of analogy between electricity and magnetism before the discovery of galvanism?—819. What other metals besides iron possess the magnetic property?—820. What are the poles of a magnet? What is the axis of a magnet? What is the equator of a magnet?—821. What is meant by the polarity of a magnet? When do two magnets attract, and when repel each other? What is understood by the dipping of the magnetic needle?—822. How is it proved that the iron attracts the magnet with the same force that the magnet attracts the iron? How does the force of magnetic attraction vary with the distance?—823. Does the magnetic force vary with the interposition of any substance between the attracting bodies?—824. What is the effect of heat on the magnet? What is the effect of electricity, or the explosion of gun-powder on it? How may the power of a magnet be increased?—825. What is said concerning the comparative powers of great and small magnets?

827. Explain Fig. 264, and describe the mode of making a magnet?—828. In what positions do bars of iron become magnetic spontaneously?—829. How may a needle be magnetized without removing it from its pivot?—830. How was the dip of the magnetic needle first discovered?—831. In what manner is the dip measured? What circumstance increases or diminishes the dip of the needle?—832. What is meant by the declination of the magnetic needle? How is this variation determined?—833. What has been ascertained concerning the variation of the needle at different times and places?

835. Is there any connection between the aurora borealis and the magnetic needle? What is said to have been the effect of lightning on the compasses of a ship at sea?—837. What is the uniting wire? If the needle is stationary, and the current flows from the north, what way will the needle turn?—838. Explain Fig. 265.—839—841. Explain figures 266, 267, and 268.—842. Explain Fig. 269.

843. Does the magnetic force of galvanism differ from any force before known, or not? In what direction does this force act, as it passes along the wire?—845. Explain by Fig. 270 in what direction the electro-magnetic fluid moves.—846. Why is mercury well adapted to show the circular action of the galvanic fluid?—847. Explain Fig. 271, and show how the pole of a magnet may be made to move in a circle.—848. In these ex-

periments, why are the ends of the conducting wires amalgamated ?—849. Explain Fig. 272.—850, 851. Explain Figures 273 and 274.

853. To produce the rotation of a magnet, on what part must the galvanism act ? Why ?—854. Explain Fig. 275, and show the course of the electrical fluid from one cup to the other.—856. How may the direction of the vibrating wire be changed ?—858. Explain Fig. 276, and describe the course of the electric fluid from one cup to the other.—860. How must the points of the vibrating wire be adjusted in order to act ?—861. Explain Fig. 277.—862. In what manner may the points of the spur-wheel be amalgamated ?—864. Explain Fig. 278, and show how two wheels may be made to revolve by the same current.

865. What is meant by magnetic induction ? Explain Fig. 279. What is this figure called ?—866. Does any substance become permanently magnetic by the action of the electrical helix ? How may the poles of a magnet be changed by the helix ?—867. How may temporary magnets be made ?—868. For what purpose are the ends of the wires to be soldered to pieces of copper ?—870. Describe the battery Fig. 281. Which is the positive and which the negative metal ?

A DICTIONARY
OF
PHILOSOPHICAL TERMS.

ABERRATION (*aberro*, to wander from). The apparent motion of the heavenly bodies, produced by the progressive motion of light and the earth's annual motion in its orbit.

ABSOLUTE EQUATION. The sum of the optic and eccentric equations.

ACCELERATION (*accelero*, to hasten). The augmentation or increase of motion in accelerated bodies.

1. *Acceleration of a planet.* A planet is said to be accelerated when its real diurnal motion exceeds its mean diurnal motion.

2. *Acceleration of the moon.* A term used to express the increase of the moon's mean motion from the sun, it being somewhat greater now than formerly.

3. *Diurnal acceleration of the fixed stars.* The time by which the stars, in one diurnal revolution, anticipate the mean diurnal revolution of the sun; which is 3° 55′ 9″.

ACHERNER. A star of the first magnitude, in the constellation Eridanus, right ascension, 22¾°, Dec. 58° 17′ S.

ACHRONYCHAL (*akros*, extreme, *nux*, night). A Greek term applied to a star, or planet, when it is opposite to the sun. A star *rises achronychally*, when it rises at sunset; and *sets achronychally* when it sets at sunrise.

ACOUSTICS (*akouo*, Gr. to hear). The science which treats of the nature, phenomena, and laws of the sense of sound. It extends to the theory of musical concord and harmony, and is, therefore, a valuable and interesting science.

ACTERAIMIN. A star of the third magnitude, in the left shoulder of Cepheus, marked *α*.

ACUBENE. A star of the fourth magnitude, in the southern claw of Cancer, marked *α*.

ADHIL. A star of the sixth magnitude, on the garment of Andromeda.

AIR. A thin, elastic fluid, surrounding the globe of the earth. The air, together with the clouds and vapours that float in it, is called the atmosphere. The height to which the atmosphere extends, has never been ascertained; but at a greater height than forty-five miles, it ceases to reflect the rays of light from the sun.

AIR-PUMP. A machine made for exhausting the air from glass vessels, for the purpose of experiment in pneumatics.

ALDEBARAN. A star of the first magnitude, in the sign Taurus. Right ascension 4 h. 25′ 35″. Dec. 16° 8′. This star frequently suffers an occultation by the moon, when the ascending node is in Virgo.

ALDHAFERA. A star of the third magnitude, in Leo.

ALGENIB. A star of the second magnitude, on the right side of Perseus.

ALGOL, or MEDUSA'S HEAD. A variable star in the constellation Perseus.

ALGORAB. A star of the third magnitude, in the right wing of Corvus.

ALLIOTH. A star of the third magnitude, in the tail of the Great Bear.

ALMACANTARS. Circles of altitude, parallel to the horizon.

ALMANAC. A calendar, wherein the days of the month, festivals, lunation, motions of the heavenly bodies, eclipses, &c. are set down for each year.

ALPHERATZ. A star of the second magnitude, in the head of Andromeda.

ALTITUDE OF A CELESTIAL BODY. The arc of a vertical circle, measured from the horizon.

AMPHISCII, or AMPHISCIANS (*amphi*, on both sides, *skia*, a shadow). A Greek designation of the people who inhabit the torrid zone, so called because they have their shadows at noon, turned sometimes one way, and sometimes another, or north and south.

AMPLITUDE (*amplus*, large). An arc of the horizon intercepted between the east or west point, and the centre of the sun or star, at its rising or setting

ANALEMMA (*analambano*, to take up). A projection of the sphere on the plane of the meridian made by straight lines and ellipses, the eye being supposed at an infinite distance, and in the east and west points of the horizon.

ANDROMEDA. A northern constellation, containing, according to Flamstead, sixty-six stars.

ANGLE. The inclination of two lines meeting one another in a point, called the *vertex*. The lines are called the legs or sides of the angle. Angles, in geometry, are called *right*, *acute*, and *obtuse*. A right angle contains just 90 degrees, or the quarter part of a circle. Acute angles contain less, and obtuse angles more, than 90 degrees.

1. *Angle of commutation*. The angle at the sun, formed by two lines, one drawn from the earth, and the other from the place of the planet reduced to the ecliptic, meeting in the sun's centre.

2. *Angle of elongation*. The angle formed by two lines drawn from the earth, the one to the sun, and the other to the planet; or it is the difference between the sun's place and the geocentric place of the planet.

3. *Angle of evection*. An inequality in the motion of the moon, by which, at or near her quadratures, she is not in the line drawn through the centres of the earth and sun, as she is at the syzygies, but makes an angle with that line of about 2° 51′.

4. *Angle of incidence*. The angle contained between the line described by the incident ray, and a line perpendicular to the surface on which the ray strikes, raised from the point of incidence.

5. *Angle of reflection*. The angle contained between the line described by the reflected ray, and a line perpendicular to the reflecting surface, at the point from which the ray is reflected.

6. *Angle of refraction*. The angle contained between the line described by the refracted ray, and a line perpendicular to the refracting surface at the point in which the ray passes through that surface.

7. *Angle of vision*. The angle contained between lines coming from opposite parts of an object and meeting in the eye.

ANGULAR MOTION. The motion of the planets about the centre of the sun, or that of the satellites about the centres of their primaries.

ANNUAL ARGUMENT. An arc of the ecliptic comprehended between the sun's place and that of the moon's apogee.

ANNUAL EPACT. The excess of the solar year above the lunar, which is 10 d. 21 h. 11 m. or nearly 11 days, which shows that the moon changes so much sooner in any month of the subsequent year, than it did the year before.

ANNUAL EQUATION. The difference between the planet's mean and true place.

ANOMALISTICAL YEAR. The

time from the sun's leaving its apogee, till it returns to it again, which is 365 days 6 h. 15 m.

ANOMALY (*anomalos*, Gr. uneven). The distance of a planet in degrees, minutes, and seconds, from the aphelion or apogee.

ANSE or ANSES. The seemingly prominent parts of the ring of Saturn, which are seen at its opening.

ANTARCTIC CIRCLE (*anti*, against, *arctos*, the bear). An imaginary line extending round the south pole, 66½ degrees from the equator, and parallel to it.

ANTARCTIC POLE. The south pole, or the southern extremity of the earth's axis.

ANTARES. The Scorpion's heart, a star of the first magnitude, in the constellation Scorpio.

ANTECEDENTIA. A term made use of to signify that a planet moves retrograde, or contrary to the order of the signs; that is, from east to west.

ANTIŒCI, or ANTŒCIANS (*anti*, against, *oikos*, a habitation). Those who live under the same meridian, and at the same distance from the equator, but one having north, and the other south latitude.

ANTIPODES (*anti*, against, *podes*, feet). The people of two places diametrically opposite to each other; they differ in longitude 180°, and one has the same latitude north, as the other has south.

APHELION (*apo*, from, *helios*, the sun). That point of a planet's orbit which is most distant from the sun. Its opposite point is the *perihelion*, which is the nearest point to the sun.

APOGEE (*apo*, from, *ge*, the earth). The sun's or the moon's greatest distance from the earth.

APPARENT (*appareo*, to appear). That which is visible or evident to the eye.

1. *Apparent conjunction of the planets* is when they have the same geocentric longitude. The apparent conjunction of the moon with any of the heavenly bodies, is their conjunction as seen from the surface of the earth.

2. *Apparent diameter of the heavenly bodies* is their angular diameter as seen from the earth, measured with a micrometer.

3. *Apparent distance of two celestial bodies* is their angular distance as seen from the earth. *Apparent* horizon is that circle which limits our sight, and has its plane parallel to the true horizon, passing through the centre of the earth.

APPULSE. The near approach of two celestial bodies to each other in angular distance, so as to be seen, for instance, within the field of a telescope.

APSES, or APSIDES (*apsis*, a circle or curvature). The two points in the orbits of the planets, or satellites, which are at the greatest and least distance from the centre of motion; and a line joining these two points is called the line of the apses.

APUS. A constellation in the southern hemisphere, containing eleven stars.

AQUARIUS. One of the zodiacal constellations, containing one hundred and eight stars.

AQUEOUS HUMOUR. The watery humour of the eye. It is the first and outermost, and that which is less dense than either the vitreous or crystalline. It is transparent and colourless like water, and fills up the space that lies between the cornea and the crystalline humour.

AQUILA. The eagle, a northern constellation containing (with Antinous) seventy-one stars.

ARA. The altar, a southern constellation, containing nine stars.

ARÆOMETER (*araios*, thin, *metron*, measure). An instrument by which the density and gravity of fluids are measured.

ARC. A part of a curved line, or circle; for example, the latitude and declination are arcs of the meridian, and longitude is the arc of the equator or parallel circle.

1. *Arc of direction* is that arc which a planet appears to describe when its motion is direct or progressive.

2. *Arc of retrogradation* is that which a planet describes whilst moving contrary to the order of the sign, or from east to west.

ARCTIC CIRCLE (*arctos*, a bear). An imaginary line extending round the north pole, 66½ degrees from the equator, and parallel to it. This and the antarctic circle are called polar circles.

ARCTURUS. A star of the first magnitude in the constellation Boötes.

ARGO NAVIS. A southern constellation, containing sixty-four stars.

ARGUMENT. An arc given, by which another may be found in some proportion to it.

Argument of latitude. An arc of the orbit of a planet, intercepted between the ascending node, and the place of the planet from the sun, according to the order of the signs.

ARIES. A constellation of fixed stars, drawn on the globe in the figure of a *ram.* It is the first of the twelve signs of the zodiac, from which a twelfth part of the ecliptic takes its name. It consists of sixty-six stars.

ARIETIS. A star of the second magnitude, in the head of the Ram.

ARMILLARY SPHERE. A name given to an artificial sphere, representing the several circles of the system of the world.

ASCENDING. A term denoting any star, degree, or any point of the heavens, rising above the horizon.

1. *Ascending latitude* is the latitude of the moon or planet when going northward.

2. *Ascending node* is the point of a planet's orbit, where it cuts the ecliptic in going northward; it is marked ☊.

ASCENSION. The rising of the sun or star, or any part of the equinoctial with it, above the horizon.

ASCENSIONAL DIFFERENCE. The difference between the right and oblique ascension, or descension; or the interval of time in which the sun rises or sets, before or after six o'clock.

ASCII (*a*, not, *skia*, shadow). The inhabitants of the torrid zone, who at certain times of the year have no shadow.

ASPECT. The situation of the stars or planets with respect to each other. There are reckoned five aspects, viz. *Conjunction*, ☌; *Sextile*, ⚹; *Quartile*, □; *Trine*, △; *Opposition*, ☍. A ☌ $=0^\circ=0^s$, *a* ⚹ $=60^\circ=2^s$, *a* □ $=90^\circ=3^s$, *a* △ $=120^\circ=4^s$, and ☍ $=180^\circ=6^s$.

ASTEROIDS (*aster*, a star, *eidos*, likeness). A general term applied by Dr Herschel to the new planets, Ceres, Juno, Pallas, and Vesta, in consequence of their being found to deviate very much in the form and position of their orbits from those of the old planets.

ASTROLABE (*astron*, a star, *lambano*, to take). A stereographic projection of the sphere upon the plane of one of the great circles. The *Sea Astrolabe* is an instrument used for the altitude of the sun and stars.

ASTROLOGY (*astron*, a star, *logos*, an account). A pretended art of foretelling future events by the aspects and positions of the stars.

ASTRONOMY (*aster*, a star, *nomos*, law). The science which teaches the motions of the earth, the sun, the moon, planets, comets, and stars, and explains the phenomena occasioned by those motions.

ASTROCOPE (*astron*, a star, *skopeo*, to look). An astronomical instrument invented by W. Shuckhard.

ATAIR. A star of the first magnitude, in the constellation of Aquila.

ATMOSPHERE (*atmos*, vapour, *sphaira*, a sphere). The fluid which surrounds our earth.

ATTRACTION. A general term, used to denote the power or principle by which bodies mutually tend towards each other, without regarding the cause or action that may be the means of producing the effect.

1. *Attraction of cohesion.* That kind of attraction which takes place between the constituent particles of the same body. By this principle bodies preserve their forms and are prevented from falling to pieces.

2. *Attraction of gravitation.* That form of attraction by which distant bodies tend towards one another.

AURIGA. The Wagoner, a northern constellation containing 66 stars.

AURORA. The morning twilight. See TWILIGHT.

AURORA BOREALIS or NORTHERN LIGHTS. A kind of meteor of a pale colour, sometimes seen in the northern parts of the heavens, supposed to be an electrical phenomenon.

AUSTRAL, SOUTHERN. The six signs of the zodiac, which are south of the equinoctial, are called *Austral signs.*

AUTUMN. The third quarter of the year, which begins when the sun enters *Libra*, that is, about the 21st or 22d of September, when the days and nights are equal.

AUTUMNAL EQUINOX. The time when the sun enters Libra, or the descending point of the ecliptic, called also the *Autumnal point.* The signs *Libra*, *Scorpio* and *Sagittarius*, are called autumnal signs.

AXIS. An imaginary line which passes through the centre of a body, and on which it turns.

1. *Axis of the earth.* An imaginary line conceived to pass through the centre of the earth from one pole to the other, about which is performed its diurnal rotation from west to east.

2. *Axis of the circles of the sphere.* Right lines supposed to be drawn through their centres, perpendicular to their planes.

3. *Axis of motion.* The line about which a revolving body moves. Philosophically speaking, the axis of motion is said to be at rest, whilst the other parts of a body move round it; and the further any part of a body is from the axis of motion, the greater is its velocity.

AXIS, IN OPTICS. That ray, among all others sent to the eye, which falls perpendicularly upon that organ, and which consequently passes through the centre of the eye.

AXIS OF A GLASS or LENS. A right line joining the middle points of the two opposite surfaces of the glass.

AZIMUTH. (Arabic). An arc of the horizon intercepted between the meridian and a vertical circle passing through the body.

AZIMUTH COMPASS. An instrument for finding the magnetic azimuth or amplitude of a celestial body.

B

B, in the astronomical tables, stands for Bissextile, or Leap-Year.

BACK STAFF. An instrument invented by Captain John Davis, a Welshman, about the year 1590; it was used for taking the sun's altitude at sea.

BALANCE. One of the simple mechanical powers by which the equality or difference of weight in heavy bodies is discovered.

BALLOON. A machine used in navigation through the air. It takes its name from the form of the machine, the word *balloon* signifying any spherical hollow body, of whatever matter it be composed, or for whatever purposes it be designed.

BAROMETER (*baros*, weight, *metron*, a measure). An instrument for measuring the weight or pressure of the atmosphere; and by that means measuring heights and depths, determining variations in the state of the air, and foretelling the changes in the weather.

BASE. The lowest side of the perimeter of a geometrical figure. Thus, the base of a triangle may be said of any of its sides, but more properly of the lowest, or that which is parallel to the horizon. In rectangled triangles, the base is properly the side opposite to the right angle.

BASS, IN MUSIC. That part of a concert which consists of the gravest and deepest sounds, and which is played on the largest pipes or strings of the instrument.

BEAR. The name of two constellations near the north pole. See URSA MAJOR and MINOR.

BEARD OF A COMET. The rays which it emits from its head in the direction of its motion.

BELLATRIX. A star of the second magnitude in the left shoulder of Orion.

BINOCLE, or BINOCULAR TELESCOPE (*bini oculi*, both eyes). A telescope by which the object can be viewed with both eyes at the same time.

BISSEXTILE, or LEAP-YEAR. A year consisting of 366 days, which happens every fourth year. The reason for adding a day every fourth year, is because the *tropical* year exceeds the *civil* year six hours. To find *Leap-year*, divide the year by four, and if nothing remains, it is Leap-Year. For instance, 1846 divided by 4, gives the quotient 461, and the remainder is two, which shows that the year 1846 is the second after Bissextile or Leap-Year, and that 1848 will be Leap-Year.

BODY. A term applied in physics, to an extended solid substance, of itself utterly passive and inactive, indifferent either to motion or rest; but capable of any sort of motion, and of all figures and forms. Body, or substance, which is the same thing, is usually denoted by the general term matter.

BOOTES. A northern constellation, containing fifty-four stars.

BOREAL SIGNS Those on the north side of the equinoctial, viz. Aries, Taurus, Gemini, Cancer, Leo, and Virgo.

BREADTH. One of the three dimensions of geometrical bodies, which, multiplied into their length, constitutes a surface.

BUBBLE. A small drop or vesicle of any fluid filled with air, and either formed on its surface, by an addition of more of the fluid, or in its substance, by an intestine motion of its component parts.

BURNING-GLASS. A convex or concave glass, commonly spherical, which, being exposed directly to the sun, collects all the rays falling thereon into a very small space, called the focus, where any combustible substance may be ignited.

C

CALENDAR. See ALMANAC. There are a great many different calendars, adapted to the various uses of common life, viz. the *Roman calendar*, the *Gregorian calendar*, the *Julian*, the *Reformed*, and the *French new calendar*, &c.

CAMERA OBSCURA. Literally, a dark chamber. It is made by placing a convex glass in a hole of a window-shutter; and, if no light enters the room but through the glass, the pictures of all objects on the outside may be distinctly seen in an inverted position, on any white surface placed at the focus of the lens.

CANCER. The Crab, one of the constellations of the zodiac; when the sun enters this sign, it has the greatest declination northward; it contains eighty-three stars.

CANIS MAJOR. The Great Dog, a southern constellation, which contains Sirius, one of the brightest fixed stars in the heavens; the number of stars in this constellation is thirty-one.

CANIS MINOR. The Little Dog,

a northern constellation consisting of fourteen stars.

CANOPUS. A star of the first magnitude, in the rudder of Argo, the ship; its right ascension is 95° and dec. 52° 36′ south, and therefore is not visible in the latitude of London.

CAPELLA. The Goat, a bright star of the first magnitude, in the left shoulder of Auriga; right ascension 75° 49′, declination 45° 48′.

CAPILLARY TUBES. Minute hair-like tubes, used for experiments in illustrating capillary attraction.

CAPRICORN. One of the twelve signs of the zodiac, represented on globes in the form of a goat.

CARDINAL POINTS. The north, south, east, and west points of the horizon.

CARDINAL SIGNS. These are Aries, Cancer, Libra, and Capricorn. The beginning of these signs are in the Cardinal points of the ecliptic.

CASSIOPEIA. A northern constellation, consisting of fifty-five stars.

CASTOR. The name of a star of the first magnitude, in the constellation Gemini.

CATALOGUE OF THE STARS. A table of the fixed stars, arranged according to their right ascensions, or longitudes, with their declinations, or latitudes, together with their annual variations and magnitudes.

CAUDA DELPHINI. A star of the third magnitude on the tail of the Dolphin, marked E.

CAUDA DRACONIS. The Dragon's tail. The moon's descending node. See DESCENDING NODE.

CAUDA LEONIS. Sometimes called *Lucida Cauda.* See DENEB.

CAUDA URSÆ MAJORIS. A star of the third magnitude, near the end of the Great Bear's tail, called also *Benenath.*

CAUDA URSÆ MINORIS. See POLE STAR.

CENTAURUS. One of the southern constellations, which contains thirty-five stars.

CENTRAL FORCES. The powers which cause a moving body to tend towards, or recede from, the centre of motion.

CENTRE OF GRAVITY. That point about which all the parts of a body, in any situation, balance each other.

CENTRE OF MOTION. That point which remains at rest, while all the other parts of a body move about it.

CENTRIFUGAL FORCE (*centrum*, the centre, *fugio*, to avoid). The force by which all bodies, that move round any other body in a curve, endeavour to fly off from the axis of their motion in a tangent.

CENTRIPETAL FORCE (*centrum*, the centre, *peto*, to seek). That force by which a body tends towards some point as a centre: such is gravity, or that force whereby bodies tend towards the centre of the earth; and that force, whatever it be, whereby the planets are continually drawn back from right-lined motions, and made to move in curves.

CERES, or PIAZZI. A primary planet moving between the orbits of Mars and Jupiter; it was discovered on the 1st of January, 1801, by M. Piazzi.

CETUS. The Whale, a southern constellation, containing ninety-seven stars.

CHARACTERS. Certain marks used in the sciences, as abbreviations. The astronomical characters are the following: *The twelve signs of the zodiac*, are ♈ Aries, the Ram; ♉ Taurus, the Bull; ♊ Gemini, the Twins; ♋ Cancer, the Crab; ♌ Leo, the Lion; ♍ Virgo, the Virgin; ♎ Libra, the Balance; ♏ Scorpio, the Scorpion; ♐ Sagittarius, the Archer; ♑ Capricornus, the Goat; ♒ Aquarius, the Water-bearer; ♓ Pisces, the Fishes. *The planets*, ☉ The Sun; ☿ Mercury; ♀ Venus; ⊕ Earth; ♂ Mars; ⚶ Vesta; ⚵ Juno; ⚳ Ceres;

⚴ Pallas; ♃ Jupiter; ♄ Saturn; ♅ Uranus. *The Aspects.* ☌ Conjunction; ⚹ Sextile; □ Quartile; △ Trine; ☍ Opposition. *The Nodes.* ☊ Ascending node; ☋ Descending node. *Motion* and *Time.* $^{\circ}$ Degree; $'$ minute; $''$ seconds; ^{h} hour; ^{m} minute; ^{s} second; A.M. Ante Meridian, or before noon; P.M. Post Meridian, or afternoon. Sometimes M. is put for morning, and A. for afternoon.

CHARLES'S WAIN. Seven conspicuous stars in Ursa Major, or the Great Bear.

CHROMATICS (*chroma*, colour). That branch of optics which explains the several properties of the colours of light and of natural bodies.

CHRONOMETER (*chronos*, time, *metron*, a measure). An instrument contrived for the purpose of measuring small portions of time; or watches used for finding the longitude are generally called chronometers, or timekeepers.

CIRCLE. A plane figure comprehended by a single curved line, called its circumference, to which right lines or radii, drawn from a point in the centre, are equal to each other.

1. *Circles of the sphere.* Circles whose planes pass through the sphere, and have their circumference upon its surface. If the plane pass through the centre of the sphere, it is called a great circle, if not, it is called a less circle. The equator and ecliptic are great circles; the polar circles and the parallels of latitude or declination, are small circles.

2. *Circles of declination.* Great circles perpendicular to the equinoctial.

3. *Circle of illumination.* That imaginary circle which divides the enlightened hemisphere of the earth from the darkened.

4. *Circles of latitude*, or *secondaries to the ecliptic.* Great circles perpendicular to the ecliptic, and intersecting in its poles.

5. *Circles of longitude.* See LONGITUDE.

6. *Circles of perpetual apparition.* Small circles parallel to the equator, and touching the horizon of any given place.

7. *Circles of perpetual occultation.* Small circles parallel to the equator, and touching the lower part of the horizon, or never appearing above it.

8. *Circles of position.* Great circles of the sphere, passing through the common intersection of the meridian and horizon, and through any degree of the ecliptic, or centre of a star or planet.

9. *Circles of altitude.* See VERTICAL CIRCLES.

CIRCULAR VELOCITY. The velocity of a revolving body, measured by an arc of a circle.

CIRCUMFERENCE. The line or lines which bound a plane figure. The term is, however, generally applied in a more limited sense, to the curved line which bounds a circle, and otherwise called a periphery; the boundary of a right-lined figure being expressed by the term perimeter.

CIRCUMPOLAR STARS. Stars which revolve round the pole, without setting in a given latitude.

CIVIL DAY. The time allotted for day in civil purposes; it begins differently in different nations; it is divided into twenty-four hours.

CIVIL MONTH. The same as given in the common almanacs.

CIVIL YEAR. That which is appointed by any government, to be used within its own dominions.

CLOCK. A well known machine for measuring time, regulated by the uniform motion of a pendulum. Common clocks are made to show mean solar time, but those used at observatories, for the purpose of observing the time of the stars transiting the meridian, show sidereal time.

CLOUDS. A collection of misty vapours suspended in the air. Their various colours and appearances are owing to their particular situation in regard to the sun, to the different reflection of the sun's rays, and to the effects produced on them by wind.

COHESION (*cohæreo*, to stick together). A form of attraction by which the particles of a body cohere.

COLUMBA NOACHI. Noah's dove, a small constellation in the southern hemisphere, consisting of ten stars.

COLOUR. That property of bodies which affects the sight only; thus, the grass in the fields has a green colour, blood has a red colour, the sky generally appears blue.

COLURES (*kolouros*, a truncated tail). Two great circles or meridians, which surround the globe from north to south, and pass through the poles of the world, cutting each other at right angles; the one is called the *equinoctial colure*, and passes through the beginning of Aries and Libra; the other, called the *solstitial colure*, passes through the beginning of Cancer and Capricorn. They divide the ecliptic into four equal parts, and make the four seasons of the year. The name probably suggests that a portion of them is always concealed from view under the horizon. But this is true of every other meridional circle.

COMA BERENICES. Berenice's hair, a northern constellation, consisting of forty-three stars.

COMET (*kometes*, from *kome*, hair). A celestial body, frequently called a blazing star, moving in a very eccentric orbit, having a vapour-like appendage. The comet moves in the planetary regions, appearing and disappearing at very uncertain intervals of time.

COMETARIUM. A machine showing the motion of a comet about the sun.

COMMUTATION. See ANGLE OF COMMUTATION.

COMPLEMENT. The distance of a star from the zenith; or the arch comprehended between the place of the star above the horizon and the zenith.

COMPLEMENT OF AN ARC OR AN ANGLE. This denotes what an arc or angle wants of 90°; thus we say, the complement of altitude or coaltitude, which is the zenith distance; the complement of latitude or declination, which is the polar distance.

COMPRESSION. The act of pressing or squeezing some matter, so as to bring its parts nearer to each other, and cause it to possess less space.

CONCAVE. A term applied to the inner surface of hollow bodies, more especially of spherical ones.

CONCORD. The relation of two sounds which are always agreeable to the ear, whether applied in succession or consonance.

CONDENSER. A pneumatic machine, whereby a considerable quantity of air may be forced into a given space.

CONDUCTORS. A term applied to long metallic rods, whose points are raised above buildings for the purpose of attracting or receiving the electric fluid, and of conducting it into the earth, or into water, thereby to prevent such buildings from being struck by lightning.

CONE. A solid geometrical figure, having a circle for its base, and its top terminated in a point or vertex.

CONJUNCTION. The meeting of two stars or planets in the same degree of the zodiac. The conjunction of two celestial bodies denotes that they have the same degree of longitude.

CONSEQUENTIA. A term applied when the planets move according to the order of the signs.

CONSTELLATION. A system of several stars which are seen in the heavens near to one another. Astronomers not only mark out the stars, but they distribute them into asterisms, or constellations, allowing several stars to make up one constellation:—and for the better distinguishing and observing them, they reduce the constellations to the forms of objects with which we are well acquainted.

CONVERGING LINES. Lines which continually approach nearer one another; or whose distance becomes still less and less.

CONVERGING RAYS. Those rays which, issuing from diverse points of an object, incline towards one another, till, at last, they meet and cross, and then become diverging rays.

CONVEX. An appeliation given to the exterior surface of gibbous or globular bodies, in opposition to the hollow inner surface of such bodies, which is called concave. Thus we say a convex lens, a convex mirror, a convex superficies.

COR CAROLI. An extra constellated star of the second magnitude; its right ascension and declination, at the beginning of 1818, was right ascension 191° 52⅓′, declination 39° 18⅓′ N.

COR HYDRÆ. The heart of Hydra; a star of the second magnitude in the constellation Hydra.

COR LEONIS or REGULUS. A star of the first magnitude in the constellation Leo.

COR SCORPIONIS. See Antares.

CORNEA (*cornu*, a horn). The second coat of the eye, so called from its substance, which resembles horn.

CORONA BOREALIS. The Northern Crown, a constellation containing 21 stars.

CORONA MERIDIONALIS. The Southern Crown. This constellation contains 12 stars.

CORVUS. The Raven, a constellation in the southern hemisphere, containing nine stars.

COSMICAL RISING AND SETTING. A term applied when a star rises or sets at the time of sunrise.

COSMOGRAPHY (*kosmos*, the universe, *grapho*, to describe). A description of the world, showing the structure of the heavens, with the disposition of the stars, and parts of the earth.

CRATER. The cup, a southern constellation consisting of thirty-one stars.

CREPUSCULUM. See Twilight

CRYSTALLINE HUMOUR. A thick compact humour, in form of a flattish convex lens, situated in the middle of the eye, serving to make that refraction of the rays of light, necessary to make them meet in the retina, and form an image thereon, whereby vision may be performed.

CULMINATION (*culmen*, the top). The transit or passage of a star over the meridian.

CURTATE DISTANCE of a planet from the earth or sun. The distance of the earth or sun from that point where a perpendicular passing the planet cuts the ecliptic.

CYCLE (*kuklos*, Gr. a circle). A certain period of time, in which the same revolutions begin again; a periodical space of time.

1. *Cycle of indiction*, or Roman indiction. This cycle has no connexion with the celestial motions; it is a period of 15 years. To find this cycle, add three to the given year, and divide the sum by fifteen, and what remains is the indiction.

2. *Cycle of the moon*, or the *lunar cycle*. A period of nineteen years, in which the new and full moons return on the same days as they did nineteen years before; this cycle is called the *Golden Number*, for the finding of which, see Golden Number.

3. *Cycle of the sun*. A period of 28 years, in which time the days of the month return again to the same days of the week, &c. See Solar Cycle.

CYGNUS. The Swan, a constellation of the northern hemisphere, containing eighty-one stars.

CYLINDER. A solid geometrical body, supposed to be generated by the rotation of a parallelogram.

D

DAY. In common language, the day is the interval of time which elapses from the rising to the setting of the sun; this is called an artificial day. The astronomical day embraces the whole interval which passes during a complete revolution of the sun.

DECLINATION. The distance of any celestial object from the equinoctial, either northward or southward. It is either true or apparent, according as the real or apparent place of the object is considered.

Declination circles. Great circles perpendicular to the equinoctial, and passing through its poles.

DEGREE. A division of a circle, including a three-hundred-and-sixtieth part of its circumference. Every circle is supposed to be divided into three hundred and sixty parts, called degrees, and each degree divided into sixty other parts called minutes; and each of these into sixty seconds.

DELPHINUS. The Dolphin, a northern constellation, containing eighteen stars.

DENEB. The Arabic term for tail; the name of several fixed stars.

DENSITY. The degree of closeness and compactness of the particles of a body; the property opposed to rarity.

DEPRESSION OF THE POLE. When a person sails or travels towards the equator, he is said to depress the pole, because as many degrees as he approaches nearer the equator, so many degrees will the pole be nearer the horizon. The phenomenon arises from the spherical figure of the earth.

DEPRESSION OF THE SUN or STAR. Its vertical distance below the horizon.

DESCENDING NODE. That point of a planet's orbit, where it cuts the ecliptic, proceeding southward, marked ☋.

DESCENSION. See Oblique and Right.

DIAGONAL (*dia*, through, *gonia*, an angle). A right line drawn across a quadrilateral figure, from one angle to another; by some called the diameter of the figure.

DIAL. An instrument to show the hour of the day by the sun.

DIAMETER (*dia*, through, *metron*, a measure). A right line passing through the centre of a circle, and terminated at each side by the circumference thereof.

DIGIT (*digitus*, a finger). The twelfth part of the diameter of the sun or moon; a term used to express the quantity of an eclipse. Thus an eclipse is said to be six digits, when six of these parts are hid.

DIMENSION. This term denotes either breadth, length, or thickness: hence a line has one dimension, *viz.* length; a superficies, two, *viz.* length and breadth; and a body, or solid, has three, *viz.* length, breadth, and thickness.

DIRECT. See Consequentia.

DIRECTION. The line or path of a body's motion, along which it endeavours to proceed, according to the force impressed upon it.

DISCORD. A dissonant and inharmonious combination of sounds, so called in opposition to concord.

DISK. The body and face of the sun and moon, such as it appears to us on the earth, or the body or face of the earth, such as it appears to a spectator in the moon. The disk in eclipses is supposed to be divided into twelve equal parts.

DISK OF THE EARTH. The difference between the horizontal parallax of the sun and moon; used in the construction of solar eclipses.

DISTANCE OF THE SUN, MOON, AND PLANETS. The real distances of any of these as found by their parallaxes.

DIURNAL. Something relating to the day, in opposition to nocturnal, which regards the night. The diurnal motion of a planet, is so many degrees and minutes as any planet moves in twenty-four hours. Hence the motion of the earth about its axis is called its diurnal motion.

1. *Diurnal arc*, is the arc described by the celestial bodies from their rising to their setting.

2. *Diurnal motion*, is the degrees, minutes, or seconds, a celestial body describes in twenty-four hours.

3. *Diurnal motion of the earth*, is its rotation on its axis.

DIVERGENT RAYS. Those rays, which, going from a point of the visible object, are dispersed, and continually depart one from another, in proportion as they are removed from the object; in which sense they are opposed to convergent rays.

DIVISIBILITY. That property by which the particles of matter in all bodies are capable of a separation or disunion from each other.

DOMINICAL LETTER. One of the first seven letters of the alphabet, wherewith the Sundays are marked in the almanacs with a red letter throughout the year.

DRACO. The Dragon, a northern constellation, containing, or consisting of, eighty stars.

DROPS. Small spherical bodies, into which the particles of fluids spontaneously form themselves, when let fall from any height.

DUBHE, or α URSA MAJOR. A star between the first and second magnitude, the most northern of the pointers.

DUCT (*ductus*). A tube or canal.

DUCTILITY. A property of certain bodies, whereby they are capable of being expanded, or stretched forth by means of a hammer or press.

DYNAMICS (*dunamis*, Gr. power). This branch of mechanics relates to the action of forces that give motion to solid bodies; which forces are calculated, both by their active powers, and by the proportion of time in which those powers become efficient.

E

EARTH, or TERRA. One of the planets: its orbit lies between Venus and Mars. Its diameter is 7914 miles, and observation proves it to be inhabited.

EARTHQUAKE. A sudden motion of the earth, occasioned, it is supposed, either by the discharge of some electrical power, or by large quantities of inflammable air, which, on being rarefied by internal fires, forces its way through the parts that surround it.

EAST. One of the four cardinal points of the world; being that point of the horizon where the sun is seen to rise when in the equinoctial.

ECCENTRIC (*ex*, out, *kentron*, the centre). A term applied to circles and spheres which have not the same centre, and consequently are not parallel; in opposition to concentric, where they are parallel, having one common centre.

ECCENTRICITY. The distance of the centre of the orbit of a planet from the centre of the sun; that is, the distance between the centre of the ellipsis and the focus.

ECHO. A sound reverberated or reflected to the ear from some solid body.

ECLIPSE (*ekleipo*, Gr. to leave out). The deprivation of the light of the sun, or of some heavenly body, by the interposition of another heavenly body between it and our sight.

ECLIPTIC. A great circle of the sphere, supposed to be drawn through the middle of the zodiac, making an angle with the equinoctial of 23 degrees 30 minutes; or it is that path among the fixed stars, that the earth appears to describe, to an eye placed in the sun, in performing its annual motion round the sun.

ELASTICITY. That disposition in bodies by which they endeavour to restore themselves to the posture from whence they were displaced by an external force.

ELECTRICITY (*electron*, amber). An invisible, subtile fluid, which appears to pervade all nature, and, among other interesting phenomena, is the cause of thunder and lightning. Electricity is of two kinds—*positive* and *negative*. The positive is that state of a body which contains more than its due proportion; and the negative is that state of a body which contains less than its due proportion. When two bodies, one charged with positive electricity and the other with negative, come in contact with each other, so much passes from the former to the latter, as to produce an equilibrium—it passes thus with a flash and an explosion. Thus two clouds, charged in the above manner, coming together, or one cloud coming in contact with the earth, thunder and lightning are produced,

ELEMENTS. Principles deduced from observation, by which tables of the planetary motions are computed.

ELEVATION OF THE POLE or STAR. The height of the pole or stars in degrees above the horizon.

ELLIPSIS (*elleipo*, Gr. to leave out). A curved line returning into itself, and produced from the section of a cone by a plane cutting both its sides, but not parallel to the base.

ELONGATION. See Angle of Elongation.

EMERSION. A term employed when any planet which is eclipsed begins to emerge or get out of the shadow of the eclipsing body. It is also used when a star, before hidden by the sun, as being too near him, begins to re-appear, or emerge out of his rays.

EPACT. See Annual and Menstrual Epacts.

EPHEMERIS (*epi*, for, *hemera*, a day). Tables containing the computations of the places of the heavenly bodies for every day at noon.

EPOCH. The same as Era, which see.

EQUATION OF THE CENTRE. See Annual Equation.

EQUATION OF THE MOON'S MEAN MOTION. This depends upon the situation of the moon's apogee and nodes with respect to the sun.

EQUATION OF TIME. The difference between apparent and mean time, or between the sun's mean motion and right ascension.

EQUATOR (*æquo*, to equal). An imaginary circle equally distant from the poles, and dividing the earth into two equal parts, one being called the Northern hemisphere, and the other the Southern hemisphere.

EQUATORAL. A very useful instrument in Astronomy, for taking the altitude, azimuth, right ascension, &c. of the heavenly bodies.

EQUINOCTIAL (*æquæ noctes*, equal nights). A great circle of the celestial globe, whose poles are the poles of the world. It is so called, because, whenever the sun comes to this circle, the days and nights are equal all over the globe; being the same with that which the sun seems to describe at the time of the two equinoxes of spring and autumn.

EQUINOCTIAL POINTS. These are *Aries* and *Libra;* and when the sun enters either of these points, it is called the equinox.

EQUINOX. The time when the sun enters either of the equinoctial points, where the ecliptic intersects the equinoctial.

ERA, or EPOCH. A fixed point of time from which to begin the computation of the ensuing years.

ERIDANUS. The River, a southern constellation, consisting of 84 stars.

EVECTION. See Angle of Evection.

EXHALATION. A general term for all the effluvia or steams raised from the surface of the earth in form of vapour. Some distinguish exhalations from vapours, expressing by the former all steams emitted from solid bodies, and by the latter, the steams raised from water and other fluids.

EXPANSION. The enlargement or increase of bulk in bodies, chiefly by means of heat.

EXPLOSION. A sudden and violent expansion of an aerial or other elastic fluid, by which it instantly throws off any obstacle that happens to be in the way, sometimes with incredible force, and in such a manner as to produce the most astonishing effects.

EXTENSION. One of the common and essential properties of body, or that by which it possesses or takes up some part of universal space, which is called the place of a body.

F

FACULÆ. Certain bright spots, frequently seen upon the disk of the sun.

FALCATED. The moon or a planet is said to be falcated, when the enlightened part appears of a crescent form like the moon or Venus, when near the sun.

FIGURE. The surface or terminating extremities of any body; considered as a property of body affecting our senses, it is defined a quality which may be perceived by two of the outward senses. Thus a table is known to be square by the sight and by the touch.

FIXED SIGNS OF THE ZODIAC. These are Taurus, Leo, Scorpio, and Aquarius; they are so called because the season is considered to be more settled when the sun passes through these signs, than at any other times of the year.

FIXED STARS. Such as do not appear to change their relative situations. They are properly called stars, in contradistinction to planets and comets.

FLUID. An appellation given to all bodies whose particles easily yield to the least partial pressure or force impressed.

FOCUS. A term applied in geometry and conic sections, to certain points in the parabola, ellipsis, and hyperbola, where the rays reflected from all parts of these curves concur and meet.

FOGS. Clouds which float on the surface of the earth, and clouds are fogs in the higher regions of the atmosphere; from many places these may be seen floating in the valleys, and often in the valleys they may be seen creeping along the sides of the mountains.

FOMAHAUT. A fixed star of the first magnitude, in the mouth of the southern fish.

FORCE. The cause of the change in the state of a body, when, being at rest, it begins to move, or has a motion which is either not uniform or not direct. Mechanical forces may be reduced to two sorts, one of a body at rest, the other of a body in motion.

FORCING-PUMP. A kind of pump, in which there is a forcer or piston without a valve.

FORE STAFF. An instrument used at sea for taking the altitudes of the celestial bodies. It is now superseded by the use of more perfect instruments.

FOUNTAIN. A spring or source of water rising out of the earth.

FRICTION. The rubbing of the parts of engines and machines against each other, by which means a great part of their effect is destroyed.

FRIGID ZONES. The spaces on the earth's surface between the polar circles and the poles.

FULCRUM. The prop or support by which a lever is sustained.

G

GALAXY (*gala*, Gr. milk). A whitish track which appears to encompass the heavens; it is very visible during a bright night, when the moon is absent.

Dr Herschel found it to consist of innumerable small stars and nebulous matter.

GEMINI. A zodiacal constellation in the northern hemisphere, containing eighty-five stars.

GEMMA, *a* CORONA BOREALIS, or ALPHACEA. A star of the second magnitude in the Northern Crown.

GEOCENTRIC (*ge*, the earth, *kentron*, the centre). A term literally signifying, having the earth for its centre.

1. *Geocentric place of a planet.* Its place as seen from the earth.

2. *Geocentric latitude of a planet.* Its perpendicular distance from the ecliptic as seen from the earth.

3. *Geocentric longitude of a planet.* Its elliptical distance from the first point of Aries, as seen from the earth.

GIBBOUS (*gibbus*, protuberant). A term used in reference to the enlightened parts of the moon, whilst she is moving from her first quarter to the full, and from the full to the last quarter.

GLOBE. A round or spherical body, more usually called a sphere, bounded by one uniform convex surface, every point of which is equally distant from a point within, called the centre.

GNOMON. An apparatus used by the ancients for finding the altitudes and declinations of the celestial bodies.

GOLDEN NUMBER, or CYCLE OF THE MOON, which see. To find the Golden Number for any year, for example, 1819: First, $1819+1=1820$; this divided by 19, gives 95, and 15 for the remainder, which is the Golden Number, as required.

GRAVITY. A term used by physical writers to denote the cause by which all bodies move towards each other, unless prevented by some other force or obstacle.

GREAT BEAR. A northern constellation. See URSA MAJOR.

GREAT CIRCLES. See CIRCLES OF THE SPHERE.

GREGORIAN CALENDAR. The reformed calendar now in use, which takes its name from Pope Gregory the XIIIth.

GREGORIAN EPOCH. The time when the Gregorian computation first took place, which was in the year 1582.

GREGORIAN TELESCOPE. A reflecting telescope, having a hole in the centre of the great speculum, through which the image is thrown by the small reflector to the eye. The distinctness of the object seen through this telescope is somewhat diminished by the hole in the great speculum.

GREGORIAN YEAR. The year now in use, called the new style; it consists of 365 days for three years, and 366 every fourth year, the same as the Julian account; but as this exceeds the tropical year by about eleven minutes and one-twentieth, and which in Pope Gregory's time amounted to ten days, he ordered so many days to be struck out of the calendar; and to prevent the like anticipation in future, it was ordered that every century not divisible by four, be reckoned common years, which in the Julian account are bissextile.

H

HAIL. A compact mass of frozen water, consisting of such vapours as are united into drops, and are frozen while they are falling. They assume various figures, being sometimes round, at other times pyramidal, cuneated, angular, thin and flat, and sometimes stellated with six radii like the small crystals of snow.

HALO. A meteor in the form of a luminous ring or circle, of various colours, appearing round the bodies of the sun, moon, or stars.

HARDNESS. The resistance opposed by a body to the separation of its particles. This property depends on the force of cohesion; and a body is considered more hard in proportion as it presents a greater resistance to the force which may be applied in order to separate its parts.

HARMONY. The agreeable result, or union, of several musical sounds, heard at one and the same time, or the mixture of divers sounds, which together have an effect agreeable to the ear. As a continued succession of musical sounds produces melody, so does a continued combination of these produce harmony.

HARMONY OF THE SPHERES. A sort of music much talked of by many of the ancient philosophers, supposed to be produced by the sweetly-tuned motions of the stars and planets. This harmony they attributed to the various proportionate impressions of the heavenly globes upon one another, acting at proper intervals.

HEAVEN. The infinite expanse in which the stars, planets, and comets, are situated, or perform their respective revolutions.

HEIGHT. A perpendicular let fall from the vertex, or top, of any right-lined figure, upon the base or side subtending it. It is likewise the perpendicular height of any object above the horizon.

HELIACAL RISING AND SETTING OF A STAR. A term applied when a star rises or sets with the sun. Or a star is said to rise heliacally when it is first seen after conjunction with the sun, and to set heliacally when it is so near the sun as to be hid by his beams.

HELIOCENTRIC PLACE OF A PLANET (*helios*, the sun, *kentron*, centre). Its latitude and longitude, or place in the heavens, as seen from the sun. The heliocentric motion of a planet is always direct, the sun being its centre of motion.

HELIOMETER (*helios*, the sun, *metron*, a measure). A kind of micrometer for measuring the diameter of the sun, moon, and stars.

HEMISPHERE (*hemi*, half, *sphaira*, a sphere). The half of a globe or sphere, when it is supposed to be cut through its centre in the plane of one of its great circles. The equator or equinoctial divides the sphere into two equal parts, called the northern and southern hemispheres.

HERCULES. A northern constellation, containing 113 stars.

HETEROSCII (*heteros*, other, *skia*, shadow). The inhabitants of the two temperate zones, whose shadows at noon are always projected the same way with regard to themselves, or always contrary ways with respect to each other.

HORIZON (*horizo*, Gr. to bound). That great circle which divides the heavens and the earth into two equal parts or hemispheres, distinguishing the upper from the lower. The horizon is either sensible or rational—the sensible horizon is that circle which terminates or bounds our view; the rational is that which divides the Starry Heavens into the upper and lower hemispheres; the stars in the upper being those that are visible, and in the lower those that are invisible to us.

HORIZONTAL. Something relating to the horizon; or that is taken in, or on a level with, or parallel to the horizon. Thus, we say, a horizontal plane.

HORIZONTAL PARALLAX. The parallax of a celestial body, when in the horizon. See PARALLAX.

HOUR. The 24th part of a natural day, answering to 15° of the equator.

HURRICANES. Violent storms, frequent in South America and the West Indies, and other hot countries, in which the wind changes in a short time to every point of the compass, and blows with a violence which scarcely any thing can resist.

HYADES (*huo*, Gr. to rain). The name of seven stars in the Bull's head, famous among the poets for the bringing of rain.

HYDRA. A southern constellation, imagined to represent a water serpent, containing sixty stars.

HYDRAULICS (*hydor*, water, *aulos*, a pipe). The science which investigates the velocity and impetus of fluids when in motion, and serves as the basis for computing the powers of various machinery acted upon by running water.

HYDROMETER (*hydor*, water, *metron*, a measure). An instrument to measure the extent and specific gravity of fluids.

HYDROSTATICAL BALANCE. A kind of balance contrived for the easy and exact finding of the specific gravities of bodies both liquid and solid.

HYDROSTATICAL PARADOX. A term denoting that any quantity of fluid, however small, may be made to balance or counterpoise any quantity, however large.

HYDROSTATICS (*hydor*, water, *statikos*, standing). The science which treats of the nature, gravity, and pressure of fluids in general, and of the methods of weighing solids in them.

I

IMAGE. The appearance of an object made either by reflection or refraction. In all plane mirrors, the image is of the same magnitude as the object, and it appears as far behind the mirror as the object is before it. In concave mirrors the image appears larger, and in those which are convex it appears less, than the object.

IMMERSION. A term applied when a star or planet is so near the sun, with regard to our observations, that we cannot see it; being as it were enveloped or hidden in the rays of that luminary. It also denotes the beginning of an eclipse of the sun or moon, when either of those bodies begins to be darkened by the shadow of the other. The term is frequently used in reference to Jupiter's satellites; when the satellite enters the shadow of the planet, it is called its immersion.

IMPENETRABILITY. That property of a body whereby it cannot be pierced by another; thus, a body which so fills a space as to exclude all others, is said to be impenetrable.

INCIDENCE (*incido*, to fall upon). The direction in which one body strikes on another.

INCLINATION. A word frequently used by mathematicians, to denote the mutual approach, tendency, or leaning of two lines, or planes, toward each other, so as to make an angle.

INCLINATION OF THE ORBIT OF A PLANET. The angle which the plane of the planet's orbit makes with the plane of the ecliptic, or earth's orbit.

INCLINED PLANE. A line or plane which makes an angle with the horizon. It is frequently used to move weights from one level to another.

INDICTION. See CYCLE OF INDICTION.

INERTIA (*iners*, inactive). That property of matter by which it would always continue in the same state of rest, or of motion in which it was put, unless changed by some external force.

INFORMED STARS. Such as were formerly not included in constellations; but modern astronomers have contrived to include all the informed stars.

INGRESS. The sun's entering any of the twelve signs, or other parts of the ecliptic.

INTEGRAL. An appellation given to parts of bodies which are of a similar nature with the whole. Thus, filings of iron have the same nature and properties as bars of iron.

INTENSITY. The degree or rate of power or energy of any quality, as of heat and cold.

J

JULIAN YEAR. The year established by Julius Cæsar, now called the old style. See GREGORIAN YEAR.

JUNO, or HARDING PLANET. One of the newly discovered planets, and the sixth in order from the sun; it was first discovered in 1804.

JUPITER. The name of one of the primary planets, remarkable for its great brightness.

L

LATITUDE (*latus*, broad). The distance of a place from the equator, or an arc of the meridian intercepted between the zenith of the place and the equator. It can never exceed 90 degrees, as that is the distance of the poles from the equator. Hence latitude is either northern or southern, according as the place, whose latitude is spoken of, is on this or that side of the equator.

LATITUDE, IN ASTRONOMY. The distance of a star or planet from the ecliptic, in degrees, minutes, and seconds, measured on a circle of latitude drawn through that star or planet, being either north or south, as the object is situated on the north or south side of the ecliptic.

LATITUDE OF THE MOON. The perpendicular distance of the moon from the plane of the ecliptic; it is north latitude, when she is on the north side of the ecliptic, and south latitude, when on the south side. It is *north ascending*, from the ascending node, to her northern limit; and *north descending*, from the northern limit to the descending node. It is *south ascending*, from her southern limit to the ascending node; and *south descending*, from the descending node to her southern limit. And the like is to be understood of the planets.

LEAP-YEAR. See BISSEXTILE.

LEE. An epithet to distinguish that half of the horizon to which the wind is directed, from the other part where it arises, which latter is accordingly called to windward.

LENS. A piece of glass or other transparent substance, which either collects the rays of light into a point, in their passage through it, or disperses them further apart, according to the laws of refraction; it is generally applied to an optic glass.

LEO. The Lion, a northern and zodiacal constellation, containing ninety-five stars.

LEO MINOR, or LITTLE LION. A modern constellation, in the northern hemisphere, containing fifty-three stars.

LEPUS. The Hare, a southern constellation, containing nineteen stars.

LEVEL. An instrument constructed for the purpose of ascertaining the exact level of any fluid, building, or any other object. Levels are of two kinds—the horizontal and the perpendicular.

LEVER. An inflexible right line, rod, or beam, supported in a single point on a fulcrum or prop, and used for the raising of weights; being either void of weight itself, or at least having such a weight as may be commodiously counterbalanced.

LIBRA (a balance). The name of one of the twelve signs of the zodiac, the sixth in order; so called because, when the sun enters it, the days and nights are equal, as if weighed in a balance.

LIBRATION (*libro*, to balance). An apparent inequality of the moon's motion, whereby she seems to librate about her axis, sometimes from the east to the west, and now and then from the west to the east; so that the parts in the western limb or margin of the moon sometimes recede from the centre of the disk, and sometimes move towards it, by which means they become alternately visible and invisible to the inhabitants of the earth.

LIGHT. The agent by which objects are made perceptible to our sense of seeing: or the sensation occasioned in the mind by the view of luminous objects.

LIGHTNING. An electrical explosion.

LIMIT OF A PLANET. This signifies its greatest heliocentric latitude.

LINE. A geometrical quantity extended in length only, without any breadth or thickness.

LIQUID. A fluid not sensibly elastic, the parts of which move on each other, and yield to the smallest impression.

LONGITUDE (*longus*, long). The distance of a place situated to the east or west of some noted meridian, as that of Greenwich: it can never exceed 180 degrees, which is half the circumference of the earth.

LOOKING-GLASSES. Plain mirrors of glass, which, being impervious to the light, reflect the images of things placed before them.

LUNAR (*luna*, the moon). Something belonging to the moon; thus we say, lunar month, lunar year, lunar dial, or lunar eclipse.

LUNAR DISTANCE. A term used in nautical astronomy, for the distance of the moon from the sun, or fixed stars; the measurement of which, whereby the true distance can be computed, is found to be of the greatest use in determining the longitude.

LUNATION. The time or period from one new moon to another—it is called the synodical month.

LUPUS. The Wolf, a constellation in the southern hemisphere, containing twenty-four stars.

LYNX. A modern constellation in the northern hemisphere, of forty-four stars.

LYRA. The Harp, a northern constellation, containing twenty-one stars.

M

MACULÆ. Dark spots that are frequently seen upon the disk of the sun.

MAGIC LANTERN. An instrument used for magnifying paintings on glass, and throwing their images upon a white screen in a darkened room.

MAGNETISM. The science which explains the properties of the loadstone, or natural magnet, which is a dark-coloured and hard mineral body, and is found to be an ore of iron, being generally found in iron mines.

MAGNITUDE. Whatever is made up of parts locally extended, or that has several dimensions; as, a line, a surface, or a solid.

MAGNITUDES. The fixed stars, according to their size or brightness, are divided into magnitudes; the brightest are called stars of the first magnitude; the next in brightness, stars of the second magnitude; and so on to the sixth or seventh magnitudes, which are the smallest that can be seen with the naked eye.

MANOMETER (*manos*, Gr. rare, *metron*, a measure). An instrument for showing or measuring the alterations in the rarity or density of the air.

MARCAB, or α PEGASUS. A fixed star of the second magnitude, near the wing of Pegasus.

MARS. The name of the planet which revolves next beyond the earth in our system; it is of a red fiery colour, and always gives a much duller light than Venus, though sometimes he equals her in size.

MATHEMATICS (*manthano*, to learn). Originally any discipline or learning; but at present the term denotes that science which teaches or contemplates whatever is capable of being numbered or measured, in so far as it is computable or measurable; and accordingly is subdivided into arithmetic, which has numbers for its object, and geometry, which treats of magnitudes.

MATTER. The general name of every substance, which has length, breadth, and thickness.

MEAN ANOMALY OF A PLANET. Its angular distance from the aphelion or perihelion, supposing it to revolve in a circle with its mean velocity

MEAN CONJUNCTION OF THE SUN AND MOON. The conjunction of their mean longitudes.

MEAN DISTANCE OF A PLANET. The semi-transverse diameter of its orbit.

MECHANICS (*mechané*, Gr. a machine). The science which treats of the laws of the equilibrium and motion of solid bodies; of the forces by which bodies, whether animate or inanimate, may be made to act upon one another; and of the means by which these may be increased, so as to overcome such as are most powerful.

MEDIUM. That space or region through which a body in motion passes to any point; thus ether is supposed to be the medium through which the heavenly bodies move; air, the medium wherein bodies move near the earth; water, the medium wherein fishes live and move; and glass is also a medium of light, as it affords it a free passage.

MELODY. The agreeable effect of different sounds ranged and disposed in succession; so that melody is the effect of a single voice or instrument, by which it is distinguished from harmony.

MENKNAR, or α CETUS. A star of the second magnitude, in the head of the Whale.

MERCURY. The name of a small star which emits a very bright white light, though, by reason of his always keeping near the sun, he is seldom to be seen; and when he does make his appearance, his motion towards the sun is so swift, that he can only be discerned for a short time.

MERIDIAN (*meridies*, mid-day). A great circle passing through the poles of the world, and both zenith and nadir, crosses the equinoctial at right angles, and divides the sphere into two hemispheres, the eastern and western; it has its poles in the east and west points of the horizon. It is called meridian, because, when the sun comes to the south part of this circle, it is then mid-day; and then the sun has his greatest altitude for that day.

METEOR. A moveable igneous body, collected in the air by means not thoroughly understood, and varying greatly in size and rapidity of motion.

METEOROLOGY. The science of studying the phenomena of the atmosphere, and that term by which are expressed all the observations that tend to make them a system.

MICROMETER (*mikros*, small, *metron*, a measure). An instrument fitted to a telescope, for the purpose of measuring small angles, such as the diameters of the celestial bodies.

MICROSCOPE. An instrument by means of which small objects are made to appear larger than they do to the naked eye.

MID-HEAVEN, or MEDIUM CÆLI. That point or degree of the ecliptic, which is upon the meridian at any time.

MILKY WAY. See GALAXY.

MINUTE. The sixtieth part of a degree of a circle. Minutes are denoted by one acute accent, thus (′); the second, or sixtieth part of a minute, is by two such accents, thus, (″); and the third by three (‴).

MIRACH, or β ANDROMEDA. A star of the second magnitude, in the constellation Andromeda.

MIRROR. Any polished body which is impervious to the rays of light, and reflects them equally. Mirrors were anciently made of metal; but at present they are generally smooth plates of glass, tinned or quick-silvered on the back part, and called looking-glasses. The doctrine of mirrors depends wholly on that fundamental law, that the angle of reflection is always equal to the angle of incidence.

MOBILITY. That property of matter by which it is capable of being moved from one part of space to another.

MOMENTUM. A term, signifying the same as impetus, or quantity of motion in a moving body; this is always equal to the quantity of matter multiplied into the velocity; or, which is the same thing, it may be considered as a rectangle under the quantity of matter and velocity.

MONOCEROS, or the UNICORN. A northern constellation, consisting of thirty-one stars.

MONSOONS. Periodical winds, frequent in the Eastern and Southern oceans, which for six months blow constantly the same way, and the contrary way the other six months. These are otherwise called *trade-winds.*

MONTH. The twelfth part of a year. A *lunar month* is the time the moon takes to describe the whole circle of the ecliptic, and is $27^d\ 7^h\ 43^m$. A *synodic month*, is the time between two conjunctions of the sun and moon, and is $29^d\ 12^h\ 44^m\ 3^s$. A *solar month* is the mean time of the sun's passing through one entire sign of the ecliptic, which is about $30^d\ 10^h\ 29^m$.

MOON. A satellite, or secondary planet, always attendant on our earth.

MOTION. The continued and successive change of place. Nothing can be produced or destroyed without motion, and every thing that happens depends on it.

MUSIC. Any succession of sounds, however much they may vary in regard to duration, or however much they may partake of various modes or keys, provided that the succession be agreeable, and excite, in a well-tuned ear, certain agreeable sensations, is called music.

MUTUAL ASPECTS. Such as the primary planets make among themselves.

N

NADIR (*nieder*, Ger. down). That point under our feet, or that point of the heavens which is diametrically opposite to the zenith, or point directly over our heads. The zenith and nadir are the two poles of the horizon.

NAPOLEON. A name given to the constellation Orion.

NATURAL PHILOSOPHY. That science, otherwise called physics, which considers the powers of nature, the properties of natural bodies, and their actions upon one another.

NEBULÆ. Luminous spots in the heavens, some of which consist of clusters of telescopic stars, others appear as luminous spots of different forms. Some of them form a round compact system, others are more irregular, of various forms, and some are long and narrow.

NIGHT. That part of the natural day during which the sun is underneath the horizon; or that space wherein it is dusky.

NOCTURNAL ARC. An arc described by a celestial body during the night.

NODES (*nodus*, a knot). The two points wherein the orbit of a planet intersects the ecliptic, whereof the node, where it ascends northwards, above the plane of the ecliptic, is called the ascending node; and the other, where the planet descends to the south, is called the descending node.

NONAGESIMAL DEGREE. The highest point of the ecliptic above the horizon; this is equal to the angle which the ecliptic makes with the horizon. It is of great use in calculation of eclipses.

NORTH. One of the cardinal points on the compass; that opposite the south.

NUMBER OF DIRECTION. A number not exceeding thirty-five, which number is the limit of Easter day, always falling between the 21st of March, and 25th of April.

NUTATION OF THE EARTH'S AXIS. A kind of vibratory motion, by which its inclination to the plane of the ecliptic is subject to a small variation.

O

OBLATE. Flattened, or shortened, as an oblate spheroid, having its axis shorter than its middle diameter, being formed by the rotation of an ellipse about the shorter axis. The oblateness of the earth refers to the diminution of the polar axis in respect of the equatorial.

OBLIQUE ASCENSION. That point of the equinoctial which rises with a celestial body in an oblique sphere.

OBLIQUE DESCENSION. That point of the equinoctial which sets with a celestial body in an oblique sphere.

OBLIQUE SPHERE. That position of the sphere in which the equator and its parallels cut the horizon obliquely.

OBSERVATORY. A place or building fitted up with proper instruments for observing the celestial bodies.

OBTUSE. Blunt, or dull, in opposition to sharp or acute. Thus we say an angle is obtuse, if it measures more than ninety degrees.

OCCIDENT. A term applied to the western quarter of the horizon, or that part of the horizon where the ecliptic, or the sun therein, descends into the lower hemisphere, in contradistinction to orient.

OCCIDENTAL. Westerly. A planet is said to be occidental when it sets after the sun.

OCCULTATION (*occulto*, to hide). The time a star or planet is hidden from our sight, by the interposition of the moon, or of some other planet.

OPACITY. A quality of bodies which renders them impervious to the rays of light.

OPPOSITION. That aspect of the celestial bodies when they are 180° from each other.

OPTICS. The science of vision, including Catoptrics and Dioptrics, and even Perspective; as also the whole doctrine of light and colours, and all the phenomena of visible objects.

ORBIT (*orbita*, a path). The path of a planet or comet, or the curve that it describes in its revolution round its central body. Thus the earth's orbit is the curve which it describes in its annual course, and usually called the ecliptic.

ORBUS MAGNUS. A term formerly used to signify the orbit of the earth.

ORIENTAL. Easterly. A planet is said to be oriental, when it rises before the sun.

ORION. The name of a constellation of the southern hemisphere, consisting of thirty-seven stars, according to Ptolemy; of sixty-two, according to Tycho; and of no fewer than eighty, in the Britannic catalogue.

ORRERY. A machine for representing the motions and appearances of the heavenly bodies. It is more properly termed a planetarium.

ORTIVE AMPLITUDE. The eastern amplitude of a heavenly body.

OSCILLATION. The vibration or reciprocal ascent and descent of a pendulum.

P

PALLAS, or OLBERS. One of the newly-discovered planets, and the eighth in order from the sun.

PARABOLA (*parabole*, Gr. juxtaposition). A geometrical figure arising from the section of a cone, when cut by a plane parallel to one of its sides.

PARADOX (*para*, beside, *doxa*, opinion). A proposition seemingly obscure, as being contrary to some received opinion, but yet true in fact.

PARALLAX (*parallaxis*, Gr. change). A change of the apparent place of any heavenly body, caused by being seen from different points of view. or it is the difference between the true and apparent distance of any heavenly body from the zenith.

PARALLAX HORIZONTAL. See HORIZONTAL PARALLAX. As the altitude of a body is affected by parallax, so is its right ascension, declination, latitude, and longitude.

PARALLEL. Those straight lines, whose least distances from each other are every where equal, are said to be parallel.

PARALLELS OF ALTITUDE. Small circles parallel to the horizon.

PARALLELS OF DECLINATION.

PARALLELS OF LATITUDE. Small circles parallel to the equinoctial or equator.

PARALLEL SPHERE. That position of the sphere in which the equator is parallel to the horizon.

PARALLELOGRAM. A quadrilateral right-lined figure, whose opposite sides are parallel and equal to each other.

PARHELION (*para*, beside, *helios*, the sun). A mock sun, or meteor, in form of a very bright light, appearing on one side of the sun.

PEGASUS. The name of a constellation of the northern hemisphere, in form of a flying horse, containing ninety-eight stars.

PENDULUM. Any heavy body so suspended that it may vibrate or swing backwards and forwards, about some fixed point, by the force of gravity. The vibrations of the pendulum are called its oscillations.

PENUMBRA (*pene*, nearly, *umbra*, a shadow). A partial shade observed between the perfect shadow and the full light, in an eclipse.

PERCUSSION. The impression a body makes in falling or striking upon another, or the shock of two bodies in motion.

PERIGEE (*peri*, around, *ge*, the earth). That point of the moon's orbit which is nearest to the earth.

PERIHELIUM (*peri*, around, *helios*, the sun). That point of a planet's or comet's orbit wherein it is at its least distance from the sun; in which sense it stands in opposition to aphelium.

PERIMETER (*peri*, around, *metron*, a measure). The bounds or limits of any figure or body. The perimeter of surfaces or figures are lines, those of bodies are surfaces. In circular figures, instead of perimeter, we say circumference, or periphery.

PERIOD. The time taken up by a star or planet in making a revolution round the sun; or the duration of its course till it returns to the same point of its orbit.

PERIŒCI (*peri*, around, *oikos*, a habitation). Those who live under the same parallel of latitude, whether north or south, but on opposite meridians.

PERIPHERY (*peri*, around, *phero*, to carry). The circumference of a circle, ellipsis, or any other regular curvilinear figure.

PERISCII (*peri*, around, *skia*, shadow). The inhabitants (if any) who live within the polar circles.

PERPENDICULAR. A line, falling directly on another line, so as to make equal angles on each side; called also a normal line.

PERSEUS. A northern constellation, containing fifty-nine stars.

PERSPECTIVE. The art of representing, upon a plane surface, the appearance of objects, however diversified, similar to what they assume upon a glass-pane, interposed between them and the eye at a given distance.

PHASES (Gr. from *phaino*, to show). The several appearances or quantities of illumination of the Moon, Venus, Mercury, and the other planets; or the several manners wherein they appear illuminated by the sun.

PHENOMENON. Any singular appearance in the heavens, as an eclipse, comet, &c.

PHŒNIX. The name of one of the constellations of the southern hemisphere, unknown to the ancients, and invisible in our northern parts. It is said to consist of thirteen stars.

PHYSICS (*physis*, Gr. nature). A term employed in natural philosophy for explaining the doctrines of natural bodies, their phenomena, causes, and effects, with their various affections, motions, and operations.

PISCES. The last of the zodiacal signs, which contains 113 stars.

PISTON. A short cylinder of metal, or other solid substance, fitted exactly to the cavity of the barrel or body of the pump. There are two kinds of pistons used in pumps, the one with a valve, and the other without a valve, called a forcer.

PLACE OF A CELESTIAL BODY. This is simply its situation in the heavens, and is usually expressed by its latitude and longitude.

PLANE. A plain surface, or one that lies evenly between its bounding lines—and as a right line is the shortest extension from one point to another, so a plain surface is the shortest extension from one line to another.

PLANET (*planetes*, Gr. a wanderer). A celestial body revolving round the sun, as a centre, and continually changing its position, with respect to the fixed stars; whence the name planet, which is a Greek word, signifying wanderer.

PLEIADES. An assemblage of seven stars in the neck of the constellation Taurus, the bull; although there are now only six of them visible to the naked eye. The largest is of the third magnitude, called "Lucido pleiadum."

PNEUMATICS (*pneuma*, wind). That branch of natural philosophy which treats of the weight, pressure, and elasticity of the air, with the effects arising from them.

POINT. This term, in geometry, as defined by Euclid, is a quantity which has no parts, or which is indivisible. Points are the ends or extremities of lines. If a point be supposed to be moved any way, it will, by its motion, describe a line.—Point, in physics, is the least sensible object of sight, marked with a pen, point of a compass, or the like. Of such points all physical magnitude consists.

POLAR. In general, something relating to the poles of the world, or poles of artificial globes.

POLARITY. The quality of a thing considered as having poles; but chiefly used in speaking of the magnet.

POLE. In astronomy, one of the extremities of the axis, on which the sphere revolves. These two points, each ninety degrees from the equinoctial or equator, are by way of eminence called the poles of the world; and the extremities of the axis of artificial globes, corresponding to these points in the heavens, are termed the poles thereof.

POLLUX. The name of a fixed star of the second magnitude, in the constellation Gemini, or the twins. The same name is also given to the hindermost twin, or posterior part, of the same constellation.

POWER. This term, in mechanics, denotes any force, whether of a man, a horse, a spring, the wind, or water, which, being applied to a machine, tends to produce motion.

PRECESSION OF THE EQUINOXES. This expression denotes a very slow motion of the equinoxes, by which they change their place, going from east to west, or contrary to the order of the signs. This motion amounts to about 50″ in a year.

PRIMARY PLANETS. Those which

have the sun for their centre of motion.

PROCYON, or α CANIS MINOR. A star of the first magnitude, in the constellation Canis Minor.

PROJECTION. The art of communicating motion to a body, thence called projectile.

PULLEY. One of the mechanical powers, called by seamen a tackle.

PUMP. A machine formed on the model of a syringe, for raising water.

PYROMETER (*pur*, fire, *metron*, a measure). An instrument for measuring the expansion of bodies by heat.

Q

QUADRANT (*quadrans*, a fourth part, or quarter). A mathematical instrument, of great service in astronomy, and, consequently, in navigation, for taking the altitudes of the sun and stars, as also for taking angles in surveying.

QUADRATURE. A geometrical term, denoting the squaring or reducing a figure to a square. That position of the moon, when she is 90 degrees from the sun.

QUADRILATERAL. A geometrical figure whose perimeter consists of four right lines making four angles, whence it is also called a quadrilateral figure. The quadrilateral figures are either a parallelogram, trapezium, rectangle, square, rhombus, or rhomboid.

QUARTILE ASPECT. See ASPECT.

R

RADIANT POINTS. Those points from whence rays of light flow in all directions.

RADIATION. The act of a body emitting or diffusing rays of light all around, as from a centre.

RADIUS. The semi-diameter of a circle, or a right line drawn from the centre to the circumference.

RADIUS VECTOR. That imaginary line connecting the planet and sun, and which, as the planet moves round the sun, describes equal areas in equal times.

RAIN. Whatever suddenly disturbs the heat or density of the air, or the electricity of the clouds, occasions the particles of vapour to rush together, and form drops of water too heavy to continue suspended in the atmosphere. They then fall in the shape of rain, and increase in size as they fall by combining with the floating vapours as they pass through them.

RAINBOW. A meteor in form of a party-coloured arch, or semicircle, exhibited only at the time when it rains. It is always seen in that point of the heavens which is opposite to the sun, and is occasioned by the refraction and reflection of his rays in the drops of falling rain.

RAREFACTION. The making a body to expand, or occupy more room or space, without the accession of new matter.

RAY. A beam of light, emitted from a radiant or luminous body.

REACTION. The resistance made by all bodies to the action or impulse of others which endeavour to change its state, whether of motion or rest.

RECEIVER. A glass vessel employed in pneumatical experiments for containing the object on which an experiment in the air-pump is to be made.

RECTANGLE. A geometrical term denoting a right-angled parallelogram.

REDUCTION. The difference between the planet's orbit, place, or argument of latitude, and ecliptic place.

REFRACTION (*refrango*, to break back). The deviation of a moving body from its direct course, occasioned by the different density of the medium in which it moves; or it is a change of direction, occasioned by a body's falling obliquely out of one medium into another of a different density. Refraction causes the heavenly bodies to appear more elevated above the horizon than they really are.

REGULUS. See COR LEONIS.

REPULSION. That property in bodies, whereby, if they are placed just beyond the sphere of each other's attraction of cohesion, they mutually fly from each other.

RESISTANCE. In general, any power which acts in an opposite direction to another, so as to destroy or diminish its effects.

RETICULA. An instrument invented for ascertaining the quantity of an eclipse.

RETINA. The expansion of the optic nerve on the internal surface of the eye, whereupon the images of objects being painted, are impressed, and by that means conveyed to the common sensory in the brain, where the mind views and contemplates their ideas.

RETROGRADE. See ANTECEDENTIA.

REVOLUTION. The period of any celestial body.

RHUMB. Any particular direction as determined by the compass.

RIGEL. A star of the first magnitude, on the left foot of Orion.

RIGHT ASCENSION. That point of the equinoctial which comes to the meridian with any celestial body, and is reckoned from the first point of Aries. The degree of the equinoctial, which rises with any celestial body in a right sphere, is called its *right ascension*, and the degree of the equator which sets with any celestial body in the said sphere, is called its *right descension*.

RIGHT SPHERE. That on which the equator and its parallels cut the horizon at right angles.

RISING OF A CELESTIAL BODY. Its appearance above the eastern horizon.

ROTATION (*rota*, a wheel). A term chiefly applied to the circumvolution of any surface round a fixed and immoveable line, which is called the axis of its rotation, and by such rotations it is that solids are conceived to be generated.

S

SAGITTA. The Arrow, a northern constellation, containing eighteen stars.

SAGITTARIUS. The Archer, one of the zodiacal constellations, containing sixty-nine stars.

SAROS or the CHALDEAN SAROS. A period of 223 lunations, in which the same eclipse returns again, within an hour or two, but not with the same degree of obscuration.

SATELLITES. Certain secondary planets, moving round the other planets, as the moon does round the earth. They are so called, because they always attend them, and make the tour about the sun with them.

SATURN. One of the superior planets, formerly considered the most distant in the solar system; it is the tenth in order from the sun.

SCHEAT, or β PEGASUS. A star of the second magnitude, in the constellation Pegasus.

SCORPIO. The Scorpion, a zodiacal constellation, containing forty-four stars.

SEASONS. The four quarters of the year, viz. Spring, Summer, Autumn, and Winter. The first quarter begins when the sun enters Aries; the second begins when the sun enters Cancer; the third, when he enters Libra; and the fourth, when he enters Capricorn.

SECOND. The sixtieth part of a minute, either of time or of motion.

SECONDARY CIRCLES, or SECONDARIES. All those circles which intersect one of the six great circles of the sphere, at right angles.

SECONDARY PLANETS. See SATELLITES.

SEGMENT OF A CIRCLE. That part of the circle contained between a chord and an arc of the same circle.

SEMICIRCLE. Half a circle, or that figure comprehended between the diameter of a circle and half the circumference.

SEMIDIAMETER. Half the diameter, or a right line drawn from the centre of a circle, or sphere, to its circumference; otherwise called the radius.

SERPENS. A northern constellation, called the Serpent of Ophiuchus; it contains sixty-four stars.

SERPENTARIUS. A northern constellation, containing seventy-four stars.

SETTING. The going down or disappearance of a celestial body in the western horizon.

SEXTANT. The sixth part of a circle, or an arc comprehending sixty degrees. The word sextant is more particularly applied to an astronomical instrument made like a quadrant, excepting that its limb comprehends only sixty degrees. The use and application of the sextant is the same with that of the quadrant.

SEXTILE ASPECT. See ASPECT.

SHADOW. A privation or diminution of light by the interposition of an opaque body; or it is a plane, where the light is either altogether obstructed or greatly weakened, by the interposition of some opaque body between it and the luminary.

SIDEREAL DAY. The time in which a star appears to revolve from any meridian to the same again, which is equal to the time of the earth's performing one entire revolution upon its axis, $23^h\ 56^m\ 4{\cdot}1^s$, of mean solar time.

SIDEREAL YEAR. The time in which the earth or sun makes one complete revolution in its orbit; that is, from any given star to the same again.

SIGNS, IN ASTRONOMY. The ecliptic is usually divided, by astronomers, into twelve parts, called signs, each of which, of course, contains thirty degrees. They are usually called signs of the zodiac; and beginning at the equinox, where the sun intersects and rises above the equator, have the following names and marks:—

Aries,	♈	Libra,	♎
Taurus,	♉	Scorpio,	♏
Gemini,	♊	Sagittarius,	♐
Cancer,	♋	Capricornus,	♑
Leo,	♌	Aquarius,	♒
Virgo,	♍	Pisces,	♓

Of these signs, the first six are called northern, lying on the north side of the equator; and the last six are called southern, being situated to the south of the equator.

SIPHON. A bended pipe, one end of which being put into a vessel of liquor, and the other hanging out of the said vessel over another, the liquor will run out from the first into the last, after the air has been sucked out of the external or lower end of the siphon, and that as long as the liquor in the upper vessel is above the upper orifice of the siphon.

SIRIUS. The dog-star, one of the brightest stars in the heavens; in the constellation Canis Major.

SKY. The blue expanse of air and atmosphere. The azure colour of the sky is attributed, by Sir Isaac Newton, to vapours beginning to condense there, and which have got consistence enough to reflect the most flexible rays.

SNOW. A well known substance, formed by the freezing of the vapours in the atmosphere. It differs from hail and hoar-frost, in being, as it were, crystallized, which they are not.

SOLAR. Something belonging to the sun; thus the solar system is that system of the world wherein the heavenly bodies are made to revolve round the sun as the centre of their motion.

SOLAR YEAR. This is of two kinds, Tropical and Sidereal, which see.

SOLID. A term applied to a body whose parts are so firmly connected together, as not to give way, or slip from each other, upon the smallest impression; in which sense solid is opposed to fluid.

SOLSTICE (*sol*, the sun, *sto*, to stand). That time when the sun is in one of the solstitial points; that is, when he is at his greatest distance from the equator; thus called, because he then appears to stand still, and not to change his distance from the equator for some time; an appearance owing to the obliquity of our sphere, and to which those living under the equator are strangers. The *solstitial points* are Cancer and Capricorn.

SOUND. The sense of hearing is effected by the pulsations or vibrations of the air, which are caused by its own expansion, or by the vibrations of sounding bodies. These sensations, or vibrations in the air, are called sounds, as are also the sensations which they produce.

SOUTH. One of the four cardinal points of the compass; when the sun is on the meridian, in northern latitudes, it is then directly south.

SPECIFIC. That which is peculiar to any thing, and distinguishes it from all others.

SPECTRUM. A term applied in optics. When a ray of light is admitted through a small hole, and received on a white surface, it forms a luminous spot. If a dense, transparent body be interposed, the light will be refracted, in proportion to the density of the medium; but if a triangular glass prism be interposed, the light is not merely refracted, but it is divided into seven different rays. This image is called the spectrum, and, from its being produced by the prism, it is termed the prismatic spectrum.

SPHERE. A solid contained under one uniform round surface, such as would be formed by the revolution of a circle about the diameter thereof, as an axis.

SPHERE ARMILLARY. See ARMILLARY SPHERE, OBLIQUE and RIGHT SPHERE.

SPHEROID (*sphaira*, a sphere, *eidos*, likeness). A solid body approaching to the figure of a sphere.

SPICA. A star of the first magnitude, in the constellation Virgo.

SPOTS, IN ASTRONOMY. Certain places of the sun's or moon's disk, observed to be either brighter or darker than the rest, and accordingly called faculæ, or maculæ.

SPRAY. The sprinkling or foam of the sea, which is driven from the top of a wave in stormy weather.

SQUARE. A quadrilateral figure, both equilateral and equiangular.

STAR. A general name for all the heavenly bodies which are dispersed throughout the whole heavens.

STARS. See PLANET, and FIXED STARS.

STATIONARY. A planet is said to be stationary, when it appears to have no motion among the fixed stars.

SUCTION. The act of sucking or drawing up a fluid, as air, water, milk, or the like, by means of the mouth and lungs.

SUMMER. See SEASONS.

SUN. The most conspicuous of the heavenly bodies, which occupies the centre of the system which comprehends the earth, the primary and secondary planets, and the comets.

SUPERFICIES, or SURFACE. A magnitude considered as having two dimensions; or extended in length and breadth, but without thickness or depth.

SYRINGE. An instrument serving to imbibe or suck in a quantity of any fluid, and to squirt or expel the same with violence.

SYZYGY (*sun*, together, *zeugnuo*, to join). A term equally used for the conjunction and opposition of a planet with the sun.

T

TANGENT. A straight line touching the circumference of a circle in one point; or a right line, which touches any arc of a curve, in such a manner as to make a right angle with the diameter of the circle of which that arc is a part.

TANTALUS'S CUP. A philosophical toy for exhibiting the principle of the siphon.

TAURUS. The name of one of the twelve signs of the zodiac, the second in order, consisting of forty-four stars, according to Ptolemy; of forty-one, according to Tycho; and of no fewer than one hundred and thirty-five, according to the Britannic catalogue.

TELESCOPE (*tele*, afar off, *skopeo*, to look). An optical instrument, used for discovering and viewing distant objects, either directly by glasses, or by reflection.

TELESCOPICAL STARS. Those stars which are not visible to the naked eye and can be only seen with a telescope.

TERMINATOR. See CIRCLE OF ILLUMINATION.

THERMOMETER (*therme*, heat, *metron*, a measure). An instrument showing the degrees of heat and cold. It is used conjointly with the barometer, for correcting the variation in the refraction, from the change of temperature and specific gravity of the atmosphere.

THUNDER. The noise occasioned by the explosion of a flash of lightning passing through the air: or it is that noise which is excited by a sudden explosion of electrical clouds, which are therefore called thunder-clouds.

TIDES. The periodical flux and reflux of the waters of the sea, supposed to be caused by the action of the sun and moon upon the ocean.

TIME. A certain measure of duration, depending upon the motion of the heavenly bodies.

TORRID ZONE. That space of the earth's surface included between the tropics.

TRADE WINDS. Certain regular winds at sea, blowing either constantly the same way, or else alternately, a certain length of time in one direction, and then as long in an opposite one. They are called trade-winds from their use in navigation, and are very common in the Indian seas.

TRANSIT (*transeo*, to pass over). The passing of a planet, just before or over the disk of another heavenly body, as the passing of Mercury or Venus over the sun's disk; the same is said of a planet or star when it passes the meridian.

TRANSMISSION. The act of a transparent body passing the rays of light through its substance, or suffering them to pass; in which sense the word is opposed to reflection.

TRANSPARENCY. A quality of certain bodies, whereby they give passage to the rays of light, in contradistinction to opacity, or that quality of bodies which renders them impervious to the rays of light.

TRIANGLE. A geometrical figure of three sides and three angles.

TROPICS (*trepo*, Gr. to turn). Two circles supposed to be drawn round the earth on each side of the equator, and 23° 29′ distant from it.

TRUE PLACE OF A PLANET. See HELIOCENTRIC PLACE.

TWILIGHT. That light, whether in the morning before sunrise, or in the evening after sunset, which is occasioned by the refraction and reflection of the sun's rays in passing through the atmosphere.

U

UMBRA. The total shadow of the earth, moon, and planets.

UNDULATION (*undula*, a little wave). A kind of tremulous motion or vibration observable in a fluid, whereby it alternately rises and falls like the waves of the sea.

UNICORN. See MONOCEROS.

UNISON. The effect of two sounds which are equal in degree of tune, or in point of gravity and acuteness.

URANUS, or HERSCHEL. A superior planet, and the most remote in the solar system.

URSA MAJOR. The Great Bear, a northern constellation, consisting of eighty-seven stars.

URSA MINOR. The Little Bear, a constellation near the north pole, which contains twenty-four stars, one of which is called the pole star.

V

VACUUM. A space empty or devoid of all matter or body.

VALVE. A kind of lid or cover of a tube or vessel, so contrived as to open one way, but which the more forcibly it is pressed the other way, the closer it shuts the aperture, so that it either admits the entrance of a fluid into the tube or vessel and prevents its return, or admits its escape and prevents its re-entrance.

VAPOUR. A thin, humid matter, which being rarefied to a certain degree by the action of heat, ascends to a particular height in the atmosphere, where it is suspended, until it returns in the form of dew, rain, snow, or hail.

VECTOR. See RADIUS VECTOR.

VEGA, or LYRA. A star of the first magnitude in the Harp.

VELOCITY. Swiftness, or that affection of motion, whereby a moving body is disposed to run over a certain space in a certain time.

VENUS. The name of the most beautiful star in the heavens, known by the names of the morning and evening star; she keeps near the sun, though she recedes from him almost double the distance of Mercury.

VERTEX. That point in the heavens directly over our heads, called the zenith. The apex of a triangle.

VERTICAL CIRCLE. A great circle perpendicular to the horizon, and passing through the zenith, and nadir of any place.

VESTA. The name of one of the small planetary bodies, discovered lately to revolve between the planets Mars and Jupiter.

VIA LACTEA. See GALAXY.

VIBRATION. A regular reciprocal motion of a body, as for example, of a pendulum which, being freely suspended, swings or vibrates from side to side.

VINDEMIATRIX. A star of the third magnitude in the constellation Virgo.

VIRGO. The name of one of the signs or constellations of the zodiac, and the sixth according to order, containing 110 stars.

VISIBLE. Something that is an object of sight or vision, or something whereby the eye is affected, so as to produce a sensation.

VISION. The act of seeing or of perceiving external objects by the organ of sight.

VOLCANOES. Mountains which emit ignited matter and smoke through apertures, communicating with cavities in the depths of the earth.

W

WATER. A transparent fluid, without colour, smell, or taste; in a very small degree compressible; and, when pure, not liable to spontaneous change.

WATER-SPOUT. An extraordinary meteor, in which a column of water is seen hanging from the clouds, and descending until it meets with a column rising from the ocean. They unite and often move with rapidity, until they meet with some opposing wind, or other cause, which destroys them.

WAVE. A volume of water elevated by the action of the wind, upon its surface, into a state of fluctuation, and accompanied by a cavity.

WEDGE. One of the mechanical powers, as they are called. The wedge is a triangular prism, whose bases are equilateral acute-angled triangles.

WEEK. A division of time consisting of seven days.

WEIGHT. A quality in natural bodies, by which they tend towards the centre of the earth.

WHEEL. One of the six powers of mechanism; which, without doubt, contributes more than any of the other five to the general convenience of mankind, by the wonderful variety of purposes, from a mill to a watch, wherein it is employed.

WHIRLWINDS. These are formed by opposite winds meeting and moving swiftly in a circle, raising sand and light bodies into the air. In the deserts of Africa they sometimes draw up the sand into a moving pillar, which buries all in its way. When they appear on the ocean, they draw up the water, and produce *water-spouts.*

WIND. When the air over any place is more heated than that around, it is rarefied or expanded, and rises. The surrounding air rushes in to supply its place, and this produces a current called wind.

X

XIPHIAS. The Sword Fish, a southern constellation, containing six stars.

Y

YEAR. The time that the sun takes to go through the twelve signs of the zodiac.

Z

ZENITH (*Arabic*). The vertical point; or a point in the heavens directly over our heads. The zenith is called the pole of the horizon, because it is ninety degrees distant from every point of that circle.

ZODIAC (*zodion*, an animal). A broad circle, about eighteen degrees in breadth, whose middle is the ecliptic, and its extremes, two circles, parallel thereto, at such a distance from it, as to bound or comprehend the excursions of the sun and planets.

ZONE (*zona*, a girdle). A division of the terraqueous globe, with respect to the different degrees of heat found in the different parts of it. There are five zones, viz., the torrid, two temperate, and two frigid zones.

ZUBENELG, or β LIBRA. A star of the second magnitude, in the constellation Libra.

ZUBENESCH, or α LIBRA. A star of the second magnitude in Libra, right ascension 220° 10′, declination 15° 16′ S.

Besides the terms commonly used in Astronomy, this Dictionary contains all the constellations, with the number of stars in each, from Mr. Flamstead's catalogue; likewise the names of the most noted stars, with their situations in the heavens. To render this Dictionary as complete as possible, the names of different astronomical instruments are also introduced; and although the explanations of the different articles are but short, yet they will be found sufficient to give the learner a just idea of the term he seeks.

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